

FORM PTO-1390 (Modified)  
(REV 11-2000)

U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

ATTORNEY'S DOCKET NUMBER

164748 (8830-26)

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR  
Not yet assigned 10/070768INTERNATIONAL APPLICATION NO.  
PCT/GB00/03431INTERNATIONAL FILING DATE  
07 September 2000PRIORITY DATE CLAIMED  
07 September 1999

## TITLE OF INVENTION

**Radar Apparatus for Imaging and/or Spectrometric Analysis and Methods of Performing Imaging and/or Spectrometric Analysis of a Substance, Dimensional Measurement, Identification and Precision Radar Mapping**

## APPLICANT(S) FOR DO/EO/US

**George Colin STOVE**

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1.  This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2.  This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3.  This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (24) indicated below.
4.  The US has been elected by the expiration of 19 months from the priority date (Article 31).
5.  A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
  - a.  is attached hereto (required only if not communicated by the International Bureau).
  - b.  has been communicated by the International Bureau.
  - c.  is not required, as the application was filed in the United States Receiving Office (RO/US).
6.  An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
  - a.  is attached hereto.
  - b.  has been previously submitted under 35 U.S.C. 154(d)(4).
7.  Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
  - a.  are attached hereto (required only if not communicated by the International Bureau).
  - b.  have been communicated by the International Bureau.
  - c.  have not been made; however, the time limit for making such amendments has NOT expired.
  - d.  have not been made and will not be made.
8.  An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9.  An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10.  An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11.  A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12.  A copy of the International Search Report (PCT/ISA/210).

## Items 13 to 20 below concern document(s) or information included:

13.  An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14.  An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15.  A **FIRST** preliminary amendment.
16.  A **SECOND** or **SUBSEQUENT** preliminary amendment.
17.  A substitute specification.
18.  A change of power of attorney and/or address letter.
19.  A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20.  A second copy of the published international application under 35 U.S.C. 154(d)(4).
21.  A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22.  Certificate of Mailing by Express Mail
23.  Other items or information:

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR Not yet assigned 1768	INTERNATIONAL APPLICATION NO. PCT/GB00/03431	ATTORNEY'S DOCKET NUMBER 164748 (8830-26)
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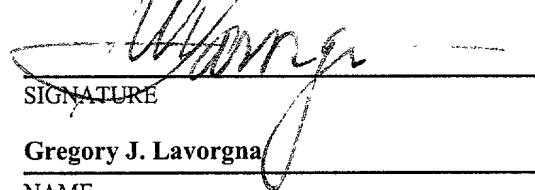
24. The following fees are submitted:		<b>CALCULATIONS PTO USE ONLY</b>	
<b>BASIC NATIONAL FEE ( 37 CFR 1.492 (a) (1) - (5) ) :</b>			
<input type="checkbox"/> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO ..... \$1040.00 <input checked="" type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO ..... \$890.00 <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO ..... \$740.00 <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) ..... \$710.00 <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) ..... \$100.00			
<b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>		\$890.00	
Surcharge of \$130.00 for furnishing the oath or declaration later than months from the earliest claimed priority date (37 CFR 1.492 (e)).		☒ 20 <input type="checkbox"/> 30	\$130.00
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE
Total claims	62 - 20 =	42	x \$18.00    \$756.00
Independent claims	3 - 3 =	0	x \$84.00    \$0.00
Multiple Dependent Claims (check if applicable)		<input type="checkbox"/>	\$0.00
<b>TOTAL OF ABOVE CALCULATIONS =</b>		<b>\$1,776.00</b>	
<input type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.		\$0.00	
<b>SUBTOTAL =</b>		<b>\$1,776.00</b>	
Processing fee of \$130.00 for furnishing the English translation later than months from the earliest claimed priority date (37 CFR 1.492 (f)).		☒ 20 <input type="checkbox"/> 30 +	\$0.00
<b>TOTAL NATIONAL FEE =</b>		<b>\$1,776.00</b>	
<input type="checkbox"/> Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable).		<input type="checkbox"/>	\$0.00
<b>TOTAL FEES ENCLOSED =</b>		<b>\$1,776.00</b>	
		Amount to be: refunded	\$
		charged	\$

- A check in the amount of \$1,776.00 to cover the above fees is enclosed.
- Please charge my Deposit Account No. \_\_\_\_\_ in the amount of \_\_\_\_\_ to cover the above fees. A duplicate copy of this sheet is enclosed.
- The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 50-0573 A duplicate copy of this sheet is enclosed.
- Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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SIGNATURE  
Gregory J. Lavorgna  
NAME  
30,469  
REGISTRATION NUMBER  
March 7, 2002  
DATE

10/070768

JCIU Rec'd PCT/PTO 07 MAR 2002  
PATENT  
Docket No.: 164748  
(8830-26)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re: Patent application of :  
George Colin STOVE :  
:  
Serial Not yet assigned : Group Art Unit:  
:  
International Serial No: PCT/GB00/03431 : Not yet known  
:  
International Filing Date: 07 September 2000 : Examiner:  
:  
For: Radar Apparatus for Imaging and/or : Not yet known  
Spectrometric Analysis and Methods of :  
Performing Imaging and/or Spectrometric :  
Analysis of a Substance, Dimensional :  
Measurement, Identification and Precision :  
Radar Mapping :  
:

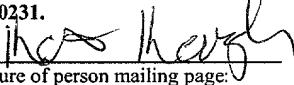
**PRELIMINARY AMENDMENT**

Commissioner for Patents

Washington, D.C. 20231

Sir:

Kindly amend the above-identified application, without prejudice, in advance of calculating the filing fee. A mark-up of the amended claims is contained in Appendix A hereto.

<b>CERTIFICATE OF MAILING UNDER 37 C.F.R. 1.10</b>	
EXPRESS MAIL Mailing Label Number: <u>EL 813788610 US</u>	
Date of Deposit: _____	
I hereby certify that this correspondence, along with any paper referred to as being attached or enclosed, and/or fee, is being deposited with the United States Postal Service, "EXPRESS MAIL-POST OFFICE TO ADDRESSEE" service under 37 C.F.R. 1.10, on the date indicated above, and addressed to: Commissioner for Patents, Washington, D.C. 20231.  Signature of person mailing page: _____	
Katie Keogh Type or print name of person	

## In the Claims

Rewrite claims 4, 8-10, 12, 16-18, 21-24, 27, 30-53, and 58-62 as follows:

4. A radar antenna assembly as claimed in Claim 2, wherein said focussing means includes at least one dielectric lens element located at said second end.
8. A radar antenna assembly as claimed in Claim 1, wherein said tubular casing has an inner diameter  $D_T$  of which is an integer multiple of the diameter  $D_A$  of said at least one antenna element.
9. (A radar antenna assembly as claimed in Claim 1, wherein said tubular casing has an interior length  $L_T$  which is an integer multiple of the length  $L_A$  of said at least one antenna element.
10. A radar antenna assembly as claimed in Claim 1, wherein an interior surface of said tubular casing comprises an antenna cathode and said elongate antenna element comprises an antenna anode.
12. A radar antenna assembly as claimed in Claim 1, including at least two elongate antenna elements, at least one of which comprises an antenna cathode and at least one of which comprises an antenna anode.
16. A radar antenna assembly as claimed in Claim 1, wherein said dielectric material is a liquid.
17. A radar antenna assembly as claimed in Claim 1, wherein said dielectric material is a solid.
18. A radar antenna assembly as claimed in Claim 1, wherein said dielectric material is a powdered solid packed into the interior of said tubular casing.
21. A radar antenna apparatus as claimed in Claim 19, wherein the base of said pyramidal structure is closed by a generally planar base wall, said chamber comprising the interior volume of said pyramidal structure.
22. A radar antenna assembly as claimed in Claim 19, wherein said chamber comprises a closed volume communicating with the open base of said pyramidal structure.
23. A radar system comprising pulsed signal generating means, transmitter antenna means, receiver antenna means, control means for controlling the operation of said pulsed signal generating

means, analog-digital converter means for digitising signals received by said receiver antenna means, and data storage means for storing said digitised signals, wherein said transmitter antenna means and receiver antenna means comprise at least one radar antenna including one of:

- (i) a tubular casing having a radar-reflective inner surface and having a first end, a second end and a longitudinal axis;
  - a radar-reflective reflector closing said first end;
  - an aperture disposed at said second end;
  - at least one elongate antenna element extending substantially parallel to said longitudinal axis from said reflector towards said second end; and
  - dielectric material substantially filling the interior volume of said tubular casing; or
- (ii) a closed chamber adapted to contain a sample of material, said chamber including four substantially triangular side walls together defining an open-based pyramidal structure, said assembly including transmitter antenna elements disposed on interior surfaces of a first opposed pair of said triangular side walls and receiver antenna elements disposed on interior surfaces of a second opposed pair of said triangular side walls.

24. A radar system as claimed in Claim 23, wherein said transmitter antenna means comprises at least one transmitter radar antenna assembly and said receiver antenna means comprises at least one receiver radar antenna said transmitter antenna assembly and said receiver transmitter assembly each comprising:

- a tubular casing having a radar-reflective inner surface and having a first end, a second end and a longitudinal axis;
- a radar-reflective reflector closing said first end;
- an aperture disposed at said second end;
- at least one elongate antenna element extending substantially parallel to said longitudinal axis from said reflector towards said second end; and dielectric material substantially filling the interior volume of said tubular casing.

27. A radar system as claimed in Claim 24, wherein said transmitter and receiver antenna assemblies are connected to a closed sample chamber adapted to enclose a subject.

30. A radar system as claimed in Claim 28, wherein said system is adapted to be portable.

31. A radar system as claimed in Claim 28, wherein said system is adapted to be carried by a land vehicle.

32. A radar system as claimed in Claim 28, wherein said system is adapted to be carried by a water-borne vessel.
33. A radar system as claimed in Claim 28, wherein said system is adapted to be carried by a submersible vehicle.
34. A radar system as claimed in Claim 28, wherein said system is adapted to be carried by an airborne vehicle.
35. A radar system as claimed in Claim 28, wherein said system is adapted to be carried by a space vehicle.
36. A radar system as claimed in Claim 28, wherein the position of said transmitter antenna assembly is fixed relative to said receiver antenna assembly.
37. A radar system as claimed in Claim 28, wherein at least one of said transmitter antenna assembly and said second antenna assembly is adapted to be movable relative to a subject.
38. A radar system as claimed in Claim 28 in which one of said transmitter and receiver antenna assemblies is adapted to be movable relative to the other.
39. A radar system as claimed in Claim 28, including a plurality of transmitter antenna assemblies.
40. A radar system as claimed in Claim 28, including a plurality of receiver antenna assemblies.
41. A radar system as claimed in Claim 28, for use with close range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse repetition frequency of the order of 100 kHz.
42. A radar system as claimed in Claim 28, for use with close range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse width in the range 0.01 to 0.1 nanoseconds.
43. A radar system as claimed in Claim 28, for use with close range subjects, adapted to capture data in a time range of 2 to 25 nanoseconds.

44. A radar system as claimed in Claim 28, for use with close range subjects, adapted to transmit pulses with a minimum frequency in the range 100 to 1000 MHz and with a maximum frequency in the range 1000 to 10000 MHz.
45. A radar system as claimed in Claim 28, for use with close to medium range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse repetition frequency of the order of 25 to 100 kHz.
46. A radar system as claimed in Claim 28, for use with close to medium range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse width in the range 1 to 10 nanoseconds.
47. A radar system as claimed in Claim 28, for use with close to medium range subjects, adapted to capture data in a time range of 2000 to 10000 nanoseconds.
48. A radar system as claimed in Claim 28, for use with close to medium range subjects, adapted to transmit pulses with a minimum frequency in the range 12.5 to 125 MHz and with a maximum frequency in the range 200 to 2000 MHz.
49. A radar system as claimed in Claim 28, for use with long range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse repetition frequency of the order of 3.125 to 50 kHz.
50. A radar system as claimed in Claim 28, for use with long range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse width in the range 10 to 25 nanoseconds.
51. A radar system as claimed in Claim 28, for use with long range subjects, adapted to capture data in a time range of 20000 to 250000 nanoseconds.
52. A radar system as claimed in Claim 28, for use with long range subjects, adapted to transmit pulses with a minimum frequency in the range 1 to 12.5 MHz and with a maximum frequency in the range 12.5 to 200 MHz.
53. A radar system as claimed in Claim 28, further including data processing means for processing said digitised signals.

58. A method as claimed in Claim 55, wherein said step of analysing said energy-frequency spectrum comprises frequency classification using energy bins.
59. A method as claimed in Claim 55, wherein said step of analysing said energy-frequency spectrum comprises energy classification using frequency bins.
60. A method of identifying an unknown subject comprising the steps of:  
obtaining an energy-frequency signature of said subject using the method of Claim 55; and  
comparing said energy-frequency signature of the unknown subject to a database of energy-frequency signatures of known subjects previously obtained using the method of Claim 55.
61. A method as claimed in Claim 55, implemented using a radar system as claimed in Claim 53.
62. A radar system as claimed in Claim 53, wherein said data processing means is adapted to perform the method of Claim 55.

2025 RELEASE UNDER E.O. 14176

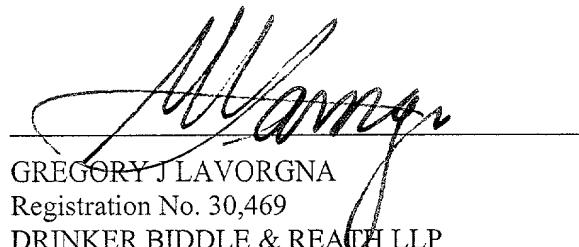
**Remarks**

Claims 1 to 24 are pending in the application. The claims have been amended to eliminate multiple claim dependencies and more closely conform them to United States practice. The specification was not amended in the international phase.

An early action on the merits is requested.

Respectfully Submitted,

George Colin STOVE



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## **APPENDIX A: Mark-up of amended claims**

4. (Amended) A radar antenna assembly as claimed in Claim 2 [or Claim 3], wherein said focussing means includes at least one dielectric lens element located at said second end.
8. (Amended) A radar antenna assembly as claimed in [any preceding Claim] Claim 1, wherein said tubular casing has an inner diameter  $D_T$  of which is an integer multiple of the diameter  $D_A$  of said at least one antenna element.
9. (Amended) A radar antenna assembly as claimed in [any preceding Claim] Claim 1, wherein said tubular casing has an interior length  $L_T$  which is an integer multiple of the length  $L_A$  of said at least one antenna element.
10. (Amended) A radar antenna assembly as claimed in [any preceding Claim] Claim 1, wherein an interior surface of said tubular casing comprises an antenna cathode and said elongate antenna element comprises an antenna anode.
12. (Amended) A radar antenna assembly as claimed in [any one of Claims 1 to 9] Claim 1, including at least two [of said] elongate antenna elements, at least one of which comprises an antenna cathode and at least one of which comprises an antenna anode.
16. (Amended) A radar antenna assembly as claimed in [any preceding Claim] Claim 1, wherein said dielectric material is a liquid.
17. (Amended) A radar antenna assembly as claimed in [any preceding Claim] Claim 1, wherein said dielectric material is a solid.
18. (Amended) A radar antenna assembly as claimed in [any preceding Claim] Claim 1, wherein said dielectric material is a powdered solid packed into the interior of said tubular casing.
21. (Amended) A radar antenna apparatus as claimed in Claim 19 [or Claim 20], wherein the base of said pyramidal structure is closed by a generally planar base wall, said chamber comprising the interior volume of said pyramidal structure.
22. (Amended) A radar antenna assembly as claimed in Claim 19 [or Claim 20], wherein said chamber comprises a closed volume communicating with the open base of said pyramidal structure.

23. (Amended) A radar system comprising pulsed signal generating means, transmitter antenna means, receiver antenna means, control means for controlling the operation of said pulsed signal generating means, analog-digital converter means for digitising signals received by said receiver antenna means, and data storage means for storing said digitised signals, wherein said transmitter antenna means and receiver antenna means comprise at least one radar antenna assembly [as claimed in any one of Claims 1 to 22] including one of:

(i) a tubular casing having a radar-reflective inner surface and having a first end, a second end and a longitudinal axis;

a radar-reflective reflector closing said first end;

an aperture disposed at said second end;

at least one elongate antenna element extending substantially parallel to said longitudinal axis from said reflector towards said second end; and

dielectric material substantially filling the interior volume of said tubular casing; or

(ii) a closed chamber adapted to contain a sample of material, said chamber including four substantially triangular side walls together defining an open-based pyramidal structure,

said assembly including transmitter antenna elements disposed on interior surfaces of a first opposed pair of said triangular side walls and receiver antenna elements disposed on interior surfaces of a second opposed pair of said triangular side walls.

24. (Amended) A radar system as claimed in Claim 23, wherein said transmitter antenna means comprises at least one transmitter radar antenna assembly [as claimed in any one of Claims 1 to 18,] and said receiver antenna means comprises at least one receiver radar antenna assembly [as claimed in any one of Claims 1 to 19], said transmitter antenna assembly and said receiver transmitter assembly each comprising:

a tubular casing having a radar-reflective inner surface and having a first end, a second end and a longitudinal axis;

a radar-reflective reflector closing said first end;

an aperture disposed at said second end;

at least one elongate antenna element extending substantially parallel to said longitudinal axis from said reflector towards said second end; and dielectric material substantially filling the interior volume of said tubular casing.

27. (Amended) A radar system as claimed in [any one of Claims 24 to 26] Claim 24, wherein said transmitter and receiver antenna assemblies are connected to a closed sample chamber adapted to enclose a subject.

30. (Amended) A radar system as claimed in Claim 28 [or 29], wherein said system is adapted to be portable.

31. (Amended) A radar system as claimed in Claim 28 [or Claim 29], wherein said system is adapted to be carried by a land vehicle.

32. (Amended) A radar system as claimed in Claim 28 [or Claim 29], wherein said system is adapted to be carried by a water-borne vessel.

33. (Amended) A radar system as claimed in Claim 28 [or Claim 29], wherein said system is adapted to be carried by a submersible vehicle.

34. (Amended) A radar system as claimed in Claim 28 [or Claim 29], wherein said system is adapted to be carried by an airborne vehicle.

35. (Amended) A radar system as claimed in Claim 28 [or 29], wherein said system is adapted to be carried by a space vehicle.

36. (Amended) A radar system as claimed in Claim 28 [or Claim 29], wherein the position of said transmitter antenna assembly is fixed relative to said receiver antenna assembly.

37. (Amended) A radar system as claimed in Claim 28 [or Claim 29], wherein at least one of said transmitter antenna assembly and said second antenna assembly is adapted to be movable relative to a subject.

38. (Amended) A radar system as claimed in Claim 28 [or Claim 29] in which one of said transmitter and receiver antenna assemblies is adapted to be movable relative to the other.

39. (Amended) A radar system as claimed in [any one of Claims 28 to 38] Claim 28, including a plurality of transmitter antenna assemblies.

40. (Amended) A radar system as claimed in [any one of Claims 28 to 39] Claim 28, including a plurality of receiver antenna assemblies.

41. (Amended) A radar system as claimed in [any one of Claims 28 to 40] Claim 28, for use with close range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse repetition frequency of the order of 100 kHz.

42. (Amended) A radar system as claimed in [any one of Claims 28 to 41] Claim 28, for use with close range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse width in the range 0.01 to 0.1 nanoseconds.

43. (Amended) A radar system as claimed in [any one of Claims 28 to 42] Claim 28, for use with close range subjects, adapted to capture data in a time range of 2 to 25 nanoseconds.

44. (Amended) A radar system as claimed in [any one of Claims 28 to 43] Claim 28, for use with close range subjects, adapted to transmit pulses with a minimum frequency in the range 100 to 1000 MHz and with a maximum frequency in the range 1000 to 10000 MHz.

45. (Amended) A radar system as claimed in [any one of Claims 28 to 40] Claim 28, for use with close to medium range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse repetition frequency of the order of 25 to 100 kHz.

46. (Amended) A radar system as claimed in [any one of Claims 28 to 40 or 45] Claim 28, for use with close to medium range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse width in the range 1 to 10 nanoseconds.

47. (Amended) A radar system as claimed in [any one of Claims 28 to 40, or 45 or 46] Claim 28, for use with close to medium range subjects, adapted to capture data in a time range of 2000 to 10000 nanoseconds.

48. (Amended) A radar system as claimed in [any one of Claims 28 to 40, or 45 to 47] Claim 28, for use with close to medium range subjects, adapted to transmit pulses with a minimum frequency in the range 12.5 to 125 MHz and with a maximum frequency in the range 200 to 2000 MHz.

49. (Amended) A radar system as claimed in [any one of Claims 28 to 40] Claim 28, for use with long range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse repetition frequency of the order of 3.125 to 50 kHz.

50. (Amended) A radar system as claimed in [any one of Claims 28 to 40 or 49] Claim 28, for use with long range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse width in the range 10 to 25 nanoseconds.

51. (Amended) A radar system as claimed in [any one of Claims 28 to 40, or 49 or 50] Claim 28, for use with long range subjects, adapted to capture data in a time range of 20000 to 250000 nanoseconds.

52. (Amended) A radar system as claimed in [any one of Claims 28 to 40, or 49 to 51] Claim 28, for use with long range subjects, adapted to transmit pulses with a minimum frequency in the range 1 to 12.5 MHz and with a maximum frequency in the range 12.5 to 200 MHz.

53. (Amended) A radar system as claimed in [any one of Claims 23 to 52] Claim 28, further including data processing means for processing said digitised signals.

58. (Amended) A method as claimed in [any one of Claims 55 to 57] Claim 55, wherein said step of analysing said energy-frequency spectrum comprises frequency classification using energy bins.

59. (Amended) A method as claimed in [any one of Claims 55 to 57] Claim 55, wherein said step of analysing said energy-frequency spectrum comprises energy classification using frequency bins.

60. (Amended) A method of identifying an unknown subject comprising the steps of:  
obtaining an energy-frequency signature of said subject using the method of [any one of Claims 55 to 59] Claim 55; and  
comparing said energy-frequency signature of the unknown subject to a database of energy-frequency signatures of known subjects previously obtained using the method of [any one of Claims 55 to 59] Claim 55.

61. (Amended) A method as claimed in [any one of Claims 55 to 60] Claim 55, implemented using a radar system as claimed in Claim 53 [or 54].

62. (Amended) A radar system as claimed in Claim 53 [or 54], wherein said data processing means is adapted to perform the method of [any of Claims 55 to 60] Claim 55.

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PCT/GB00/03431

WO 01/18533

1

JC10 Recd PCN/PTO 07 MAR 2002

21/PNTS

1 Radar Apparatus for Imaging and/or Spectrometric  
2 Analysis and Methods of Performing Imaging and/or  
3 Spectrometric Analysis of a Substance for Dimensional  
4 Measurement, Identification and Precision Radar Mapping  
5  
6 This invention relates to radar apparatus and methods  
7 of use thereof for imaging and/or spectrometric  
8 analysis. In particular, it relates to pulsed radar  
9 apparatus for magnifying, imaging, scale measuring,  
10 identifying and/or typecasting the composition of a  
11 substance by radargrammetric imaging and/or  
12 spectrometric analysis. The invention further relates  
13 to the use of the radar apparatus to locate and/or  
14 distinguish a substance from other substances. The  
15 invention may additionally be used to image a  
16 substance/feature and to monitor the movement of an  
17 imaged substance/feature. Such moving  
18 substances/features include but are not limited to the  
19 flow of blood and other substances moving within a  
20 human or animal body, and substances/features in a

1 subterranean environment, such as the movement of  
2 water, oil, gas and/or contaminants below the ground  
3 surface, below standing or flowing water bodies, or  
4 below sea level and the seabed.

5

6 Radar systems and methods in accordance with the  
7 invention can be adapted for a variety of applications  
8 at a wide range of scales and distances. These vary  
9 from large scale, long range applications such as  
10 airborne, seaborne and ground based geophysical  
11 imaging/analysis of the Earth's surfaces and sub-  
12 surfaces, for example precision mapping and  
13 classification of sea-bed materials and also soil,  
14 sediment and rock type mapping and classification to  
15 medium scale, medium range applications such as "ground  
16 level" (on land or water bodies) imaging/analysis such  
17 as sea-bed and ground penetrating applications at  
18 relatively shallow depths, to the small scale such as  
19 material typecasting applications and small scale  
20 (including microscopic) imaging/analysis, including  
21 biological and medical imaging and diagnostic  
22 applications. The invention might also be extended to  
23 very long range/large scale space based imaging and  
24 analysis applications, such as orbital surveying of  
25 planets and astronomical applications.

26

27 The scale (i.e. range and resolution) the radar  
28 apparatus operates on is determined to a greater or  
29 lesser extent by the geometry of transmitting and  
30 receiving antenna apparatus employed in systems  
31 according to the invention. It is also affected by the

1 properties of dielectric materials employed in such  
2 apparatus.

3

4 Certain aspects of the invention concern certain  
5 conditions being achieved during the set up of the  
6 apparatus so as to obtain "standing wave oscillations"  
7 in sample chambers and/or in antenna assemblies. In  
8 this respect it is important to selectively control the  
9 group velocity of the radiation as it is emitted or  
10 "launched" by the transmitter into the surrounding  
11 medium. In particular, for deep scanning it is  
12 important for the launch speed of the wave to be  
13 sufficiently slow to ensure that the wave can be  
14 accurately registered at a precise "zero time" location  
15 by the receiver after the pulse has been transmitted.  
16 The zero time position is the start position for range  
17 measurements and must be identified on the received  
18 radar signal to determine the true range represented by  
19 the received signal.

20

21 Setting up the standing wave oscillations for different  
22 time ranges or time windows such as, for example, 25  
23 ns, 50 ns, 100 ns, 1000 ns or 20,000 ns, would all  
24 involve different zero time locations. Different time  
25 ranges are required to enable the different depth  
26 ranges required for certain precision mapping  
27 applications to be obtained. Accurate location of the  
28 zero time point is important and can be a difficult  
29 procedure: inaccurately pinpointing the zero time  
30 introduces a systematic shift in the location of all  
31 radar measurements. Certain embodiments of the  
32 invention register the zero time location prior to the

1 received radar signal being converted from analogue to  
2 digital form. This enables a more accurate zero time to  
3 be located than can be obtained by using conventional  
4 techniques. Preferred embodiments of the invention  
5 locate the optimum position for time zero, for mapping  
6 or "staring" operations, by digital means using  
7 mathematical logic.

8

9 A blind spot of the order of 1 meter in close proximity  
10 (the near range) to the radar apparatus could generate  
11 an equivalent position shift in the radar map of  
12 features detected. Such near range blind spots can  
13 thus be highly undesirable. By accurately locating the  
14 position of the zero time point in the received signal  
15 radar, such blind spots can be mitigated or obviated.

16

17 Although ground penetrating radars (GPRs) are already  
18 known as non-destructive testing tools their analytical  
19 capabilities have been restricted and imaging is often  
20 crude using conventional devices. Conventional radar  
21 systems which use electromagnetic waves to investigate  
22 the internal structure of non-conducting substances  
23 within the ground provide relatively low resolution.  
24 Furthermore, they are often unwieldy devices and  
25 require skilled technical operators.

26

27 The apparatus, systems and methods of the invention may  
28 be used for a variety of purposes, particularly but not  
29 exclusively three basic types of application. The  
30 first of these relates to identifying or "typecasting"  
31 unknown materials using their spectral characteristics;  
32 i.e. using energy-frequency characteristics, and may be

1 referred to generally as "typecasting" operations. The  
2 second relates to use of the equipment in the field or  
3 laboratory, for detecting and/or mapping and/or  
4 measuring and/or analysing structures or materials, for  
5 example; these may be referred to generally as  
6 "surveying" operations. The third relates to use of  
7 the apparatus to locate materials previously typecast,  
8 and to search for them in the field or laboratory and  
9 may be referred generally to as the "searching"  
10 operations. The various types of operation are  
11 supported by suitable software which enables the field  
12 or laboratory imaging and analysis processes to be  
13 performed in near real time.

14

15 The inventor believes that a key feature of the  
16 invention is the set up of resonant conditions in the  
17 transmitter/receiver apparatus. This is affected by  
18 the dimensions and/or the geometry of a transmitter  
19 cavity and a receiver cavity which substantially  
20 surround respective transmitting and receiving  
21 antennae. In particular, the relative proportions of  
22 the lengths and widths of the antenna element(s) to the  
23 lengths and widths of the surrounding cavities are  
24 important. Ideally the internal diameter of an antenna  
25 cavity, whose walls may form the cathode element of an  
26 antenna in certain embodiments, is an integer multiple  
27 of the diameter of the internal antenna anode element,  
28 and similarly, the internal length of the is ideally an  
29 integer multiple of the length of the antenna anode  
30 element. The resonant conditions may be further  
31 affected by at least partially cladding the antennae  
32 element(s) with a suitable dielectric cladding

1 material. Furthermore, the selection of a suitable  
2 dielectric material to clad the transmitting and  
3 receiving antenna elements is believed to further  
4 assist in the near range focusing and in more  
5 accurately pin-pointing the zero time position, the  
6 start position for range measurements.

7

8 The invention seeks to provide radar apparatus having a  
9 transmitter which is capable of emitting a beam of  
10 electromagnetic radiation into or towards a substance  
11 and a receiver which is capable of receiving  
12 electromagnetic radiation which has passed through or  
13 been reflected from the substance. The radiation is  
14 preferably a pulsed radar type signal. The radar  
15 signal may be provided by a conventional pulsed radar  
16 unit. The radar apparatus includes a suitable tuning  
17 means which is capable of controlling the spectral  
18 characteristics, for example the power and bandwidth,  
19 of the emitted radar signal. The spectral  
20 characteristics of the emitted radar signal are  
21 controlled so that by suitably irradiating a substance,  
22 a frequency response dependent on the composition of  
23 the substance can be detected by the receiver.

24

25 Suitable substances whose composition and/or structure  
26 can be detected by the apparatus include solids,  
27 liquids and composite substances such as powders, soil  
28 or sediment. Liquid substances may be admixtures  
29 and/or emulsions (e.g. air/oil etc.).

30

31 The spectrometric analysis of the data acquired by the  
32 radar apparatus is performed on a computer which is

1 capable of running a suitable software program to  
2 implement the required analysis.

3

4 The frequency response obtained by irradiating a  
5 substance displays characteristics which the inventor  
6 believes are at least partially dependent on the  
7 interaction of the transmitted signal with the sub-  
8 atomic structure of the substance to be analysed. The  
9 radar apparatus may further include suitable filter  
10 devices to control the spectral characteristics, for  
11 example bandwidth and/or polarisation, of the signals.

12

13 Optionally, the radar signal may be transmitted into a  
14 chamber capable of holding a sample of the substance.

15

16 In certain embodiments of the invention, the  
17 transmitted signal is controlled so that resonant  
18 conditions, i.e. standing waves, are set up within the  
19 radar apparatus. Preferably, the resonant conditions  
20 occur within transmitting/receiving cavities  
21 surrounding the antennae. Further resonant conditions  
22 may be generated within the substance and/or within a  
23 chamber enclosing the substance. Such resonant  
24 conditions may be established by selectively tuning the  
25 parameters of the emitted signal until the spectrum of  
26 the received signal indicates resonant conditions.

27

28 The radar apparatus is preferably configured so as to  
29 be capable of providing a highly collimated or  
30 selectively focussed beam over a desired range.

31

1 The boundary conditions for resonant standing waves are  
2 at least partially dependent on the surface boundaries  
3 of the substance itself, and may be further affected by  
4 any internal structure within the substance. Composite  
5 materials, for example, may exhibit more complex  
6 boundary conditions which can enable the structure of  
7 the substance to be determined; for example, the degree  
8 of granularity of a powdered sample may be determined  
9 to some extent using the radar apparatus.

10  
11 The invention, in its various aspects, variants and  
12 optional and preferred features, is defined in the  
13 Claims appended hereto.

14  
15 Embodiments of the invention will now be described, by  
16 way of example only, with reference to the accompanying  
17 drawings in which:

18  
19 Fig 1 is a block diagram of a radar system embodying  
20 one aspect of the present invention;

21  
22 Fig 2 is a block diagram of a preferred embodiment of a  
23 radar system similar to that of Fig. 1;

24  
25 Figs. 3A and 3B are cross-sections of test chambers  
26 incorporating receiving and transmitting antennas  
27 embodying another aspect of the invention;

28  
29 Fig. 4 is an exploded internal plan-view of the test  
30 chamber illustrated in Fig. 3A;

31

1 Fig. 5A is a cross-sectional side view of an antenna  
2 assembly for use as a transmitter or receiver embodying  
3 a further aspect of the invention;

4

5 Fig. 5B is a cross-sectional side view of a first  
6 variant of the antenna assembly of Fig. 5A;

7

8 Fig. 5C is a cross-sectional side view of a second  
9 variant of the antenna assembly of Fig. 5A;

10

11 Fig. 5D is a cross-sectional side view of a third  
12 variant of the antenna assembly of Fig. 5A;

13

14 Fig. 5E is a cross-sectional side view of an antenna  
15 assembly for use as a transmitter or receiver, similar  
16 to that of Fig. 5A;

17

18 Figs. 5F to 5N are schematic end views illustrating  
19 variants of antenna assemblies of the type shown in  
20 Fig. 5E;

21

22 Fig 6A is a cross-sectional view of radar apparatus set  
23 up for chamber mode operation according to one  
24 embodiment of the invention;

25

26 Fig. 6B is a cross sectional view of apparatus set up  
27 according to a variation of the embodiment of Fig. 6A;

28

29 Fig. 7A illustrates an example of an arrangement of  
30 radar apparatus for operation in a reflection mode in  
31 accordance with a further embodiment of the invention;

32

1 Fig. 7B illustrates a further arrangement of radar  
2 apparatus for operation in a transillumination mode in  
3 accordance with a further embodiment of the invention;

4  
5 Figs. 8A to 8D are sketches which illustrate various  
6 embodiments of the invention suitable for the remote  
7 detection and/or imaging and/or typecasting of  
8 substances/objects;

9  
10 Fig. 9 is a sketch illustrating an embodiment of radar  
11 apparatus in accordance with the invention suitable for  
12 sea-bed scanning;

13  
14 Fig. 10 is a sketch illustrating another embodiment of  
15 apparatus embodying the invention suitable for sea-bed  
16 scanning;

17  
18 Fig. 11A shows an example of a microscope fitted with  
19 transmitting and receiving antenna assemblies in  
20 accordance with a further embodiment of the invention.

21  
22 Fig. 11B illustrates the relative movement of a  
23 transmitting antenna and receiving antenna in  
24 accordance with a further embodiment of the invention.

25  
26 Fig. 12 is a table summarising various parameters as  
27 used in a variety of embodiments of the invention.

28  
29 Fig. 13 is an image recorded using the radar apparatus  
30 according to the invention.

31

1 Firstly, apparatus embodying various aspects of the  
2 invention will be described.

3

4 Fig. 1 is a generic block diagram illustrating the  
5 basic architecture of radar systems in accordance with  
6 the invention. A pulsed radar unit 21 is powered by a  
7 power supply 20. The radar unit 21 is connected to a  
8 transmitting ("Tx") antenna assembly or antenna array 2  
9 and to a receiving ("Rx") antenna assembly or antenna  
10 array 3. The radar unit 21 may be of a conventional  
11 type, suitably a Ground Penetrating Radar (GPR) set,  
12 capable of providing controlled signal pulses to the Tx  
13 antenna assembly 2 and of receiving and processing  
14 return signals received by the Rx antenna assembly 3  
15 and includes suitable input/output means to transmit  
16 and receive pulsed signals. The general configuration,  
17 controls etc. of radar sets of this type will be well  
18 known to persons skilled in the art and will not be  
19 described in detail herein. The controls of the radar  
20 unit 21 enable the characteristics of the transmitted  
21 pulse to be controlled, such characteristics including,  
22 for example, the pulse profile, width, duration and  
23 energy. For the purposes of the present invention, the  
24 radar set 21 acts primarily as a pulse generator for  
25 driving the Tx antenna.

26

27 The radar unit 21 is connected to an analog/digital  
28 (A/D) converter 22 and control unit 25, for controlling  
29 the operation of the radar unit 21 and for receiving  
30 analog signals received by the radar unit via the Rx  
31 antenna 3 and for converting the analog signals to  
32 digital form. The A/D converter and control unit 22, 25

1 are in turn connected to signal processing and display  
2 means 23, typically comprising a suitably programmed  
3 personal computer, with associated data storage means  
4 of any suitable type(s) (hard disk and/or tape  
5 and/or writable CD-ROM etc.). The computer 23 generally  
6 includes a suitable visual display device (not shown).

7

8 The power supply means 20 may be a mains supply, or a  
9 generator and/or a battery supply. The power supply  
10 means 20 may be provided internally within the pulse  
11 generation unit 21 or externally. Typically, the power  
12 supply means 20 is a 12 volt DC supply which may be a  
13 mains supply converted to 12 V DC, or alternatively,  
14 especially in portable embodiments of the invention, be  
15 a 12V generator and/or a 12V DC battery supply.

16

17 The radar unit, A/D converter and control unit and the  
18 computer may be combined in a variety of configurations  
19 in custom built apparatus. As illustrated, the system  
20 preferably comprises a standard radar unit, a standard  
21 computer with software suited to the methods of the  
22 present invention, and a purpose built A/D converter  
23 and control unit.

24

25 The computer is suitably a ruggedised portable computer  
26 (laptop) with a suitably powerful processor, e.g. a  
27 Pentium-type processor, and adequate memory (RAM) and  
28 mass storage capacity.

29

30 The A/D converter 22 is preferably designed so that in  
31 use it is capable of receiving at least three signal

1 inputs. An additional signal input, for example a voice  
2 data input, may also be provided.

3

4 The system is operable in at least one of three general  
5 modes of operation, in accordance with the invention:  
6 "chamber" modes in which a sample of material under  
7 investigation is enclosed in a chamber, the Tx antenna  
8 being arranged to irradiate the interior of the chamber  
9 and the Rx antenna being arranged to receive signals  
10 modified by the interaction of the transmitted signals  
11 with the chamber and its contents; "transillumination"  
12 modes in which the Tx antenna is arranged to transmit  
13 signals through a sample of material or an object, body  
14 or structure etc. under investigation and the Rx  
15 antenna is arranged to receive signals which have  
16 passed through the sample, object etc.; and  
17 "reflection" mode in which the Rx antenna receives  
18 signals transmitted by the Tx antenna and reflected by  
19 a sample, object, body or structure etc. These various  
20 modes of operation will be discussed in more detail  
21 below. The various modes of operation are used for a  
22 variety of imaging, mapping, measuring and typecasting  
23 functions, as shall also be described in more detail  
24 hereinafter.

25

26 Fig. 2 illustrates a preferred embodiment of a multi-  
27 purpose radar system in accordance with the invention  
28 which can employ a variety of types of transmitting and  
29 receiving antennas, antenna assemblies or antenna  
30 arrays, including the preferred antennas and antenna  
31 assemblies described hereinbelow.

32

1 Referring to Fig. 2, the system comprises a radar  
2 control unit (RCU) 500, a computer 506, a transmitter  
3 unit 507, a receiving unit 508, a transmitting antenna  
4 550, a receiving antenna 552 and a power supply 519.

5

6 The RCU has its own motherboard with a processor 501,  
7 DMA controller 502, a buffer memory module 503 and an  
8 input/output controller 504, all linked to a system bus  
9 505. The I/O controller 504 is directly connected to  
10 the external computer 506, which controls all digital  
11 set-ups, data storage and data analysis. The RCU 500  
12 provides the timing signals for controlling the  
13 transmitting and receiving units 507 and 508, which are  
14 directly linked to the transmitting and receiving  
15 antennas 550, 552. The antennas 550, 552 may be single  
16 or multiple elements. The timing signals are  
17 controlled by parameters output from the computer 506  
18 to the RCU 500. The RCU 500 also relays digitised data  
19 from the receiver unit 508 back to the computer 506.  
20 The RCU 500 consists of analogue and digital logic with  
21 a programmable central processing unit (CPU) 501.

22

23 The RCU sets up a Pulse Repetition Frequency (PRF).  
24 The transmitter unit 507 essentially consists of a  
25 pulse generator 512 designed to produce strong pulses  
26 with characteristics, including the PRF, determined by  
27 the RCU. The pulse is limited by the high voltage,  
28 current and power required. Extending the pulse width  
29 reduces the voltage and current needed for the same  
30 average pulse energy. Too short a pulse will produce  
31 too much high frequency energy which is not necessary  
32 for certain applications in which high frequencies are

1       absorbed more than the lower frequencies in the subject  
2       under examination (e.g. the ground in sub-surface  
3       ground applications). Higher frequencies may be  
4       required for other applications including shallow range  
5       modes of operation (e.g. for microscopic slide scanning  
6       applications in medical tissue studies).

7

8       In the transmitter unit 507, the pulse is triggered by  
9       a digital "Trig in" pulse sent from the RCU 500, via a  
10      PRF module 509 which channels the Trig in pulse through  
11      a fixed delay line 510. The Trig in pulse 511 is  
12      responsible for triggering the transmitted pulse in the  
13      transmitter unit 507. A delay/gain control 513 in the  
14      RCU 500 controls a gain control 514 to generate a fixed  
15      time varying gain (TVG) and fixed delay line 510 for  
16      the transmitter unit 507. The same delay/gain control  
17      513 operated upon by the PRF module 509 also creates a  
18      variable TVG for the receiver unit amplifier 518 and a  
19      variable delay line 515 for a sample and hold module  
20      516 of the receiver unit 508. The rate at which pulses  
21      are transmitted is referred to as the pulse repetition  
22      frequency (PRF) and the PRF module 509 sets the  
23      required PRF for each particular mode of operation of  
24      the system. The PRF must be long enough to allow  
25      analogue to digital (A/D) conversion to be performed by  
26      the A/D converter 517 of the receiver unit 508 and to  
27      cover the required time window for the particular  
28      instrument measuring application.

29

30      The receiver unit 508 includes a low noise amplifier  
31      518 which amplifies the analogue signal received via  
32      the receiver antenna 552, which is sampled by the

1 sample and hold module 516 and digitised by the A/D  
2 converter 517 when requested by a digital signal from  
3 the RCU 500.

4

5 The A/D converter 517 is responsible for analogue to  
6 digital sampling and the digital sampling frequency  
7 should ideally be no greater than the time spacing  
8 between picture elements (pixels) of the output signal  
9 data. A smaller sampling interval results in aliasing  
10 (i.e. increasing noise) of the signal. A longer  
11 sampling interval attenuates the higher frequency  
12 components of the signal. The advantage of the  
13 variable TVG from the gain control 514 to the receiver  
14 amplifier is that the A/D conversion may be performed  
15 to the same precision with a lower number of bits.

16

17 The digital data obtained from the A/D converter enable  
18 real-time analysis of

- 19 i) a positioning fix sign or chainage mark, enabling  
20 the location of a substance/image to be determined;
- 21 ii) imaging signal information;
- 22 iii) typecasting information - i.e. the spectral  
23 characteristics of the scanned substance/object;
- 24 iv) a voice-over to be further recorded from the user  
25 via a suitable microphone as a digital signal.

26

27 In use of the radar apparatus, the A/D converter  
28 converts the received signal from analogue format to a  
29 12-bit digital signal and combines this with a synch  
30 pulse and electronic fix data. The signal is buffered  
31 and synchronised with a 16 bit computer signal to

1 condition the data. Image data are converted into 8-bit  
2 image files.

3

4 The computer 506 controls the overall functions of the  
5 other units and provides a user interface for the  
6 selection of control and survey parameters, data  
7 collection, data enhancement, image production, image  
8 analysis, material typecasting, material testing and  
9 data logging etc..

10

11 The entire radar system is powered either by mains  
12 power 519 or battery power conversion 520.

13

14 There are four primary signal, data and control  
15 linkages between the components of the system:  
16 transmitter 507 to receiver 508, RCU 500 to transmitter  
17 507, receiver 508 to RCU 500, and RCU 500 to computer  
18 506. The transmitter to receiver linkage is via the  
19 antennas 550, 552 and intervening media such as air or  
20 other gases, water or other liquids, the ground, vacuum  
21 etc. There may also be unintentional transmitter-  
22 receiver linkage through RCU-transmitter cables and  
23 receiver-RCU cables if they are conducting. When this  
24 occurs, touching the cables may cause an electrical  
25 short which can affect output data. The RCU-  
26 transmitter and receiver-RCU linkages will generally be  
27 metal or glass fibre, but can be wireless connections  
28 such as radio or optical through vacuum and/or gaseous  
29 and/or liquid media. Metal is preferably avoided for  
30 the above mentioned reasons. The RCU-computer linkage  
31 will normally be a serial or parallel port connection,  
32 since the required data rates are not unusually high.

1 Other possible links include USB, PCMCIA, IrD or radio  
2 modem.

3

4 Examples of various antennas and antenna assemblies,  
5 embodying further aspects of the invention, will now be  
6 described, which are particularly suited for the  
7 purposes of the invention when operated in one or more  
8 of its various modes.

9

10 Figs. 3A, 3B and 4 illustrate examples of  
11 antenna/chamber assemblies suited for chamber mode  
12 operations in accordance with the invention,  
13 particularly for typecasting applications performed on  
14 material samples or relatively small objects.

15

16 Fig. 3A shows a cross-section through a sample  
17 irradiation chamber 100a which has a preferred  
18 pyramidal geometry. Fig. 3B shows a cross-section  
19 through a sample irradiation chamber 100b which has an  
20 upper section with a pyramidal geometry similar to that  
21 of Fig. 3A but with a rectangular chamber extending  
22 downwardly from the base of the pyramid. Fig. 4 shows  
23 an exploded overhead view of the embodiments  
24 illustrated in Figs. 3A and 3B indicating the antenna  
25 configuration.

26

27 The cross-section along lines X-X' of Fig. 4 is  
28 illustrated in Fig. 3A. In Fig. 4. A transmitting  
29 antenna 102 and a receiving antenna 103 are directly  
30 provided within the chambers 100. Fig 3A shows the  
31 configuration of the transmitting antenna 102 in  
32 profile. A cathode feed connector wire 111 connects a

1 cathode half of a transmitting bowtie dipole element  
2 115a to the pulse generator of the system. An anode  
3 feed connector wire 112 connects the anode half of the  
4 transmitter bowtie element 115b provided on the  
5 opposite internal face of the chamber 100 to the  
6 receiver side of the system.

7

8 Fig. 4 illustrates the orientation of a receiving  
9 cathode bowtie dipole component 120a and connecting  
10 cathode feed connector wire 118 and a receiving anode  
11 bowtie dipole component 120b and connecting anode feed  
12 connector wire 119.

13

14 To increase the detection of cross-polarised  
15 reflections and to reduce the detection of other  
16 reflections, the receiver dipole components 120a, 120b  
17 are orientated at 90° to the transmitter dipole  
18 components 115a, 115b.

19

20 To ensure that a sample of material 116 placed within  
21 the chamber 100 (as Fig. 3A and 3B show) is  
22 sufficiently irradiated, the chamber 100 is provided  
23 with a suitable geometry to enhance the internal  
24 reflection and is suitably sealed to eliminate  
25 radiation leaks. Alternatively the chamber and/or  
26 transmitter/receiver tubes are vacuum sealed. A wall  
27 113a or base 113b of the chamber 100 is configured so  
28 that access to the interior is provided so as to enable  
29 the sample 116 to be placed inside. For example, the  
30 entire base 113b of the chamber 100 may be detachable.

31

1 Radiation shielding of the interior and the elimination  
2 of any radiation leaks from the interior is provided by  
3 the selection of suitable construction materials for  
4 the chamber 100. For example, the walls 113a and base  
5 113b of the chamber 100 may be constructed from an  
6 insulating material such as plastic, and may be bonded  
7 externally or internally to an electrically conducting  
8 material such as copper 114. Alternatively, the base  
9 113b may be made of a metallic substance to optimise  
10 base reflections.

11

12 In the Fig. 3B chamber, to ensure that the optimal  
13 number of reflections occur in the chamber interior,  
14 the rectangular side walls 122 are preferably provided  
15 with a metallic inside surface. This enables omni-  
16 directional backwall and base reflections from the  
17 transmitted radiation to penetrate the sample. The  
18 geometry of the chamber 100 is preferably selected to  
19 maximise the irradiation of the sample. As Figs. 3A  
20 and 3B show, the primary direction of the radiation  
21 pattern is orientated to and from the walls 113, base  
22 123 and the sample 116.

23

24 Figs. 5A to 5D are cross-sectional side views of  
25 preferred embodiments of antenna assemblies in  
26 accordance with one aspect of the invention which can  
27 be deployed as receivers and/or transmitters in various  
28 systems and methods embodying the invention. These  
29 embodiments are applicable to all of the various  
30 operational modes and functions in accordance with the  
31 various aspects of the invention; i.e. chamber,  
32 transillumination and reflection modes and

1 imaging/mapping and typecasting functions. The  
2 configuration of the antenna assemblies is scalable  
3 over a wide range of dimensions for different  
4 applications.

5

6 At the front end 203 of the assembly, a focusing system  
7 is provided by a suitable lens device 204, for example  
8 of the type of a Fresnel Zone Plate (FZP) lens. The  
9 FZP lens comprises two concentric slit-ring apertures  
10 224, 225 separated by a ring spacer 226, for example a  
11 metallic (e.g. polished brass) front-end internal  
12 reflecting ring. The main body of the assembly  
13 consists of a tube 227, preferably having a reflective  
14 metallic composition, for example polished brass or  
15 stainless steel. A back wall reflector 232 is provided  
16 in the form of a concave metallic ring (again polished  
17 brass or any other suitably reflective material may be  
18 used) which is bonded to the tube 227 and to a cathode  
19 connector 233. Through the centre of the backwall  
20 reflector 232 protrudes an anode element 230, which is  
21 preferably a narrow hollow tube element, for example  
22 comprising copper, and which is separated from the  
23 grounded cathode walls of the assembly by insulating  
24 material 231.

25

26 The diameter  $D_A$  of the anode element 230 is preferably  
27 an exact multiple of the internal diameter  $D_T$  of the  
28 tube 227. The un-insulated portion of the anode element  
29 230 also protrudes into the interior of the tube 227 by  
30 a distance  $L_A$  which is preferably an exact multiple of  
31 the total reflecting distance  $L_T$  from the back wall  
32 reflector 232 to the front wall reflecting ring 226.

1  
2 For example, an anode width of 2 mm and a tube inner  
3 diameter of 10 mm gives a ratio  $D_A:D_T$  of 1:5. Ideally,  
4 the ratios between the anode diameter and the tube  
5 diameter are integers and similarly the ratios between  
6 the anode length and the tube length are integers. In  
7 this case, an anode length  $L_A$  of 19.05mm and a tube  
8 inner length  $L_T$  of 190.5 mm between the back wall  
9 internal reflector 232 and front wall internal  
10 reflector 226 gives a longitudinal standing wave ratio  
11 parameter of  $L_A:L_T$  of 1:10. This balances the lateral  
12 ratio parameter  $D_A:D_T$  of 1:5 to achieve optimum standing  
13 wave resonance in the tube, before the wave is launched  
14 through the aperture.

15  
16 These proportions are selected to optimise resonant  
17 reflection conditions in the assembly. The resonant  
18 amplification effect and the propagation of signals  
19 through the assembly is further optimised by the  
20 appropriate selection of a dielectric cladding material  
21 228 which substantially fills the interior of the tube  
22 227 (and, preferably, the interior of the tube forming  
23 the anode 230, in order to maximise the effective  
24 dielectric constant of the assembly for a given  
25 dielectric material). The cladding material 228  
26 preferably has a high dielectric constant to provide an  
27 optimum resonant amplification through the antenna  
28 assembly. The dielectric material may be a liquid or a  
29 solid or a mixture thereof. Preferably, the dielectric  
30 material comprises a powdered solid packed within the  
31 interior of the tube 227.

1 An anode feed wire connects the anode element connector  
2 236 to a highly resistive (e.g. 75 Ω) lead cable 235.  
3 The back reflector 232 is grounded by connecting a  
4 ground wire from the lead cable 235 to the cathode  
5 element connector 237.

6  
7 The configuration of the assembly is such that the  
8 transmitted energy radiated from the anode 230 is  
9 highly collimated within the body of the assembly.  
10 When the assembly is used as a transmitter the  
11 concentric focussing ring slits 224, 225 at the  
12 transmitting end have the effect of focussing the  
13 collimated beam exiting the assembly at a predetermined  
14 distance from the exit aperture. Depending on the  
15 configuration of the focussing ring slits, and/or the  
16 use of additional focussing elements such as dielectric  
17 lens attachments described below, the characteristics  
18 of the transmitted beam can be modified so that the  
19 focal distance of the assembly may be varied over a  
20 wide range, effectively from the exit aperture to  
21 infinity, for different applications.

22  
23 Fig. 5B shows an antenna assembly similar to that of  
24 Fig. 5A, which further includes a cylindrical  
25 dielectric lens element 238 with planar end surfaces.  
26 This type of lens attachment modifies the beam leaving  
27 the assembly in a manner which depends on the distance  
28 of the outer end surface of lens attachment relative to  
29 the inherent focal distance of the main assembly, and  
30 on the refractive index and dielectric properties of  
31 the lens attachment relative to those of the dielectric

1 cladding material inside the assembly and relative to  
2 those of the external medium/media into which the beam  
3 is transmitted from the device. This embodiment is  
4 particularly useful when the lens surface is located at  
5 the inherent focal distance of the assembly and placed  
6 in contact with a surface under examination, acting as  
7 a spacer element for precise focussing.

8  
9 Fig. 5C shows a further antenna assembly similar to  
10 that of Fig. 5A. In this case the assembly is fitted  
11 with a cylindrical plano-concave dielectric lens 239.  
12 As compared with the embodiment of Fig. 5B, this type  
13 of lens attachment further modifies the beam depending  
14 on the geometry of the concave surface, in addition to  
15 its refractive and dielectric properties. A beam  
16 emerging from the embodiment of Fig. 5A will diverge  
17 beyond the focal distance of the assembly. A plano-  
18 concave lens of this type may be configured to reduce  
19 such divergence or to re-focus the beam or to collimate  
20 the beam.

21  
22 Fig. 5D shows still another antenna assembly similar to  
23 that of Fig. 5A. In this case the assembly is fitted  
24 with a cylindrical plano-convex dielectric lens 240.  
25 This type of lens attachment will have an effect  
26 opposite to that of Fig. 5B. When the assembly is used  
27 as a receiver, it will increase the capacity of the  
28 assembly to collect incident radiation.

29  
30 In the embodiments of Figs. 5A to 5D, the tubular body  
31 of the assembly acts as the cathode of the antenna and  
32 the anode extends along the central longitudinal axis

1 of the tube. Fig. 5E shows an alternative embodiment,  
2 similar to that of Fig. 5A except that both the anode  
3 and cathode both comprise elongate, preferably tubular,  
4 elements 602, 604 located inside the outer tube 606,  
5 parallel to and arranged symmetrically about the  
6 longitudinal axis thereof. The dimensions  
7 (particularly the lengths and diameters) of the anode  
8 and cathode elements 602 and 604 are preferably  
9 proportional to the corresponding dimensions of the  
10 tube 606, as with the anode of the embodiments of Figs.  
11 5A - 5D. Also, the spacings between the elements 602  
12 and 604 and between the elements and the outer tube 606  
13 are similarly in proportion.

14

15 The arrangement of the antenna elements 602 and 604 in  
16 Fig. 5E allows a pair of similar antenna assemblies to  
17 be cross polarised relative to one another since the  
18 assemblies can be rotated about their longitudinal axes  
19 such that the planes in which the elements 602 and 604  
20 of each assembly lie can be arranged at right angles to  
21 one another.

22

23 The number and arrangement of anode and cathode  
24 elements within the antenna assemblies may be varied,  
25 as illustrated in Figs. 5F to 5N, which are schematic  
26 end views of antenna assemblies similar to those of  
27 Fig. 5E with different arrangements of elements. Figs.  
28 5F and 5I show assemblies similar to those of Fig. 5E  
29 with one anode and one cathode element 602 and 604. In  
30 Fig. 5F, the elements are oriented at right angles to  
31 those of Fig. 5I. Figs. 5G, 5H 5J and 5K show  
32 assemblies with multiple anode and cathode elements

1 arranged in linear arrays along a diameter of the outer  
2 tube of the assembly, with Figs. 5G and 5H showing the  
3 arrays oriented at right angles to those of Figs. 5J  
4 and 5K. Figs. 5L to 5N show further embodiments with  
5 multiple elements arranged in cruciform arrays, the  
6 elements being located along two diameters of the tube  
7 at right angles to one another. In such embodiments,  
8 the arrangement of anodes and cathodes may vary. For  
9 example, the elements along one diameter may all be  
10 anodes and the elements along the other diameter may  
11 all be anodes, or the elements located along two  
12 adjacent radii may be anodes and the elements located  
13 along the other two radii may be cathodes, allowing  
14 different polarisations of respective assemblies.  
15 Pairs of assemblies may be oriented with the planes of  
16 their arrays disposed at relative angles other than 90°,  
17 such as 45°, so as to provide other relative  
18 polarisations. Electrical connections to the various  
19 elements may be switchable so that a single assembly  
20 may be selectively configured with different  
21 arrangements of anodes and cathodes. In all cases, the  
22 relative dimensions and spacings of the elements and  
23 the outer tube are preferably in proportion as  
24 previously described.

25

26 The various basic modes of operation of radar systems  
27 in accordance with the invention will now be described.

28

29 Figs. 6A and 6B illustrate "chamber" modes, in which a  
30 sample of material or the like is enclosed in a  
31 chamber. These embodiments operate by  
32 "transilluminating" the sample. The embodiments of

1 Figs 3 and 4 are also intended for chamber mode  
2 operation, but do not transilluminate the sample in the  
3 same way as the embodiments of Figs 6A and 6B.

4

5 Referring now to Fig. 6A, a cross-section of two  
6 antenna assemblies similar to those of Fig. 5E is  
7 illustrated, arranged for chamber mode operation.

8

9 The apparatus shown generally at 1 consists of a  
10 transmitter assembly 2 and a receiver assembly 3  
11 aligned substantially coaxially with a chamber 4  
12 provided in co-alignment therebetween.

13

14 The transmitter 2 and receiver 3 each consist of a  
15 cavity 5a and 5b respectively, for example a hollow  
16 tube or pipe. Within the tube 5a, an anode 6a and  
17 cathode 7a form a transmitting antenna 8a which is  
18 disposed in longitudinal alignment with the tube axis  
19 XX'. Within tube 5b, an anode 6b and cathode 7b form a  
20 receiving antenna 8b which is disposed in longitudinal  
21 alignment with the tube axis XX'.

22

23 Within each tube 5a, 5b, the anodes 6a, 6b and cathodes  
24 7a, 7b are substantially surrounded by a cladding  
25 material selected for its dielectric properties. For  
26 example, the antennae 8a, 8b can be immersed in  
27 distilled water which is used as a dielectric cladding.  
28 Other alternatives include mixtures of distilled water  
29 and sand, or any other substance having the desired  
30 dielectric properties. Each tube 5a, 5b is suitably  
31 sealed at each end 12a, 13a and 12b, 13b respectively.

1 A suitable sealant is, for example, a resin or other  
2 electrically insulating substance,

3

4 Focusing means 9a, 9b are provided adjacent to the  
5 chamber 4. In this case, each of the focusing means 9a  
6 or 9b comprises a dielectric lens of a selected  
7 geometry and dielectric composition to enable the  
8 radiation emitted/received by the respective  
9 transmitting antenna 8a or collecting antenna 8b to be  
10 converged/diverged as it enters/exits the chamber 4  
11 respectively. For example, in this first embodiment of  
12 the invention, the lenses 9a, 9b of the transmitter and  
13 receiver respectively are both selected to have a wax  
14 composition with a high resistivity, for example, of  
15 the order of  $10^9$  Megohm-meters.

16

17 The relative dimensions of each anode 6a, 6b to the  
18 corresponding cathode 7a, 7b and the surrounding  
19 dielectric material and/or tube 5a, 5b are determined to  
20 be fractionally proportional to each other as  
21 previously described. For example, the width of the  
22 anode 6a is proportional to the width of the cathode 7a  
23 and to the interior diameter of the tube 5a and the  
24 length of the anode 6a is proportional to the overall  
25 length of the tube 5a.

26

27 It is believed that such geometrical scaling between  
28 the antenna and the surrounding cladding, together with  
29 the dielectric properties of the cladding, assists the  
30 formation of resonant standing wave oscillations.  
31 Standing wave oscillations set up within the dielectric  
32 material contained within the transmitting tube 5 can

1 assist in the intensification and collimation of the  
2 emitted radiation. Under such conditions, the  
3 transmitter 2 provides a means of generating a resonant  
4 and collimated beam of radiation at selected  
5 wavelengths which the receiver 3 is capable of  
6 detecting.

7

8 The overall geometry of the transmitter 2 and receiver  
9 are therefore related to the size and scale of  
10 resolution required. The dielectric properties of the  
11 cladding material selected to surround the antennas 8a,  
12 8b are also important in this respect as these will  
13 affect the group velocity  $V_g$  of the radiation  
14 emitted/received.

15

16 In the embodiment illustrated in Fig. 6A, the  
17 transmitter 2 and receiver 3 are arranged in coaxial  
18 alignment so that the sample chamber 4 is  
19 transilluminated.

20

21 To typecast a substance by determining its spectral  
22 characteristics, other selection criteria may be used  
23 to determine suitable antenna cladding materials and  
24 the relative dimensions and overall size of the antenna  
25 assemblies. In each case the object is to ensure  
26 sufficient spectral detail is obtained at the desired  
27 resolution and scale. To ensure optimum conditions, it  
28 is preferable for the widths/lengths of the tubes 5a,5b  
29 to be integral multiples of the widths/lengths of the  
30 internal antennas 8a and 8b respectively.

31

1     Returning to Fig 6A, in this embodiment of the  
2     invention the radar equipment 1 is operated to  
3     typecast/identify a sample 10 placed within the chamber  
4     4. The chamber 4 in this embodiment is disposed in two  
5     parts: a lower portion 4a attached to the transmitter 2  
6     and an upper portion 4b attached to the receiver 3.  
7     The sample 10 is placed in the lower portion 4a.  
8     For example, the chamber may have an internal diameter  
9     of 40 mm and an internal depth of 40mm above the tube  
10    base.

11  
12    In this embodiment, the tubes 5a,5b may each have an  
13    internal diameter of 16mm, and the chamber 4 is  
14    positioned so that the overall inner transmission  
15    length of the transmitter tube 5a and chamber portion  
16    4a is 330mm and the overall receiver length of the  
17    receiving tube 5b and chamber portion 4b is 295mm. The  
18    measurements in each case are parallel to the direction  
19    XX' and are measured from the contact interface between  
20    the lower chamber portion 4a and the upper chamber  
21    portion 4b when the chambers contact each other in the  
22    transillumination configuration. For a required  
23    internal chamber volume, the dielectric lenses 9a, 9b  
24    are selected to optimise the convergence/divergence of  
25    radiation emitted by the antenna assemblies 2,3 and the  
26    sample chamber portion 4a is located within a maximum  
27    distance from the transmitter 2, preferably no more  
28    than 300mm.

29  
30    In the embodiment illustrated in Fig. 6A, each antenna  
31    8a, 8b may be a multi-folded YAGI array with two  
32    insulated groups containing a plurality of individually

1 screened high quality copper elements in the  
2 longitudinal tube plane XX'. Each array is filled with  
3 the selected dielectric material, such as distilled  
4 water in this example, to make a dielectrically clad  
5 bistatic antenna pair. The above configuration enables  
6 an optimum impedance match to be obtained at 50 ohm.  
7

8 The radiation emitted by the transmitting antenna 8a is  
9 focused by means of the wax lens 9a so that the sample  
10 placed in the lower portion of the chamber 4a is  
11 irradiated. Each wax lens 9a, 9b in this embodiment  
12 extends 4mm into the base of the chamber portions 4a,  
13 4b respectively. The receiving portion of the chamber  
14 4b is filled with a suitable dielectric, for example,  
15 air. The radiation is refocussed by the wax lens 9b  
16 into the receiving antenna assembly 2 where it is  
17 detected by the receiving antenna 8b.

18  
19 In this embodiment, the size of the chamber 4 limits  
20 the size of objects to be examined: apart from this  
21 limitation a variety of substances may be typecast  
22 ranging, for example, from solid materials or  
23 composites, liquids, gases, soils, sediments or powder  
24 samples. For example, wood powders, soils, flours and  
25 oils. Both organic and non-organic substances can be  
26 typecast.

27  
28 As an example, if the total volume of the sample  
29 chamber 4 is 45ml, a sample of, for example, 25ml of  
30 the substance to be typecast may be placed within the  
31 lower portion of the chamber 4a. Air occupies the

1 remaining 20ml volume of space inside the upper chamber  
2 portion 4b.

3

4 To ensure that stray e.m. radiation is reduced to a  
5 minimum, suitable e.m. shielding is provided. For  
6 example, by selecting a conductive, metallic substance  
7 (e.g. aluminium) to form the tubes 5a,5b and chamber  
8 portions 4a,4b and/or by further sheathing the metallic  
9 substance with a suitable insulating material (e.g.  
10 plastic). The provision of a layer of insulating  
11 material and conductive material is as is known in the  
12 art such that stray e.m. fields etc. are substantially  
13 eliminated.

14

15 The transmitter antenna assembly 2 is used to generate  
16 a resonant collimated beam of pulsed radar signals.  
17 These pulsed signals are set up and controlled by a  
18 pulse generator unit as previously described in  
19 relation to Figs. 1 and 2. In this example, the  
20 bandwidth of the transmitted pulse may be of the order  
21 of 2 MHz to 200 MHz. A large enough time window is  
22 employed to ensure that sufficient reflections have  
23 occurred within the telescopes 2, 3 and the chamber 4.  
24 For example, a time window of 16ns can be used with a  
25 pulse interval time of 100ms.

26

27 Fig. 6B shows another embodiment which is a variation  
28 of the arrangement of Fig. 6A. In Figs. 6A and 6B,  
29 like reference numerals designate like or equivalent  
30 components and features. In this embodiment, the  
31 transmitting and receiving antenna assemblies 2 and 3  
32 are again aligned in transillumination mode, with an

1 enclosed chamber 4 which completely contains and  
2 conceals a sample container 400 for specimen  
3 typecasting. In this example the transmitting and  
4 receiving antenna assemblies may be similar to those of  
5 Figs. 5A and 5B. This embodiment differs from that of  
6 Fig. 6A in that interior cavities of the tubes 5a and  
7 5b are packed with a high dielectric material, such as  
8 barium titanate, for which  $\epsilon_r$  equals 4000 at room  
9 temperature. Within the tubes 5a, 5b, the anodes 6a,  
10 6b are located centrally, extending along the axis X-  
11 X', and the cathodes 7a, 7b are provided by the inner  
12 walls of the tubes 5a, 5b.

13

14 The focussing means 9a, 9b preferably touch the top and  
15 bottom respectively of the sample container 400. In  
16 this case, the focussing means 9a, 9b comprises two  
17 concentric slit-ring apertures 224a, 224b, 225a and  
18 225b, separated by a spacer 226a, 226b, as described  
19 above in relation to Fig. 5.

20

21 The chamber 4 in this case comprises two metallic solid  
22 cells 4a, 4b screwed together to form a sealed radio  
23 frequency (RF) shielded unit. The cells 4a, 4b are  
24 preferably made from non-magnetic metals, such as  
25 aluminium or brass, for example.

26

27 This arrangement of the typecasting chamber has been  
28 optimised to substantially eliminate stray  
29 electromagnetic fields.

30

1 The bandwidth of the signals received depends on the  
2 size and configuration of the antennas 8a, 8b and the  
3 sample chamber 4. If the sample substance is to be  
4 typecast, its spectral characteristics are determined  
5 by subtracting the signal received from the apparatus  
6 under resonant conditions when the sample chamber 4 is  
7 empty from the signal received under similar conditions  
8 when a substance to be typecast is placed within the  
9 chamber 4. The spectral characteristics of the  
10 resultant data may then be compared with the spectral  
11 characteristics of known materials which have  
12 previously been obtained in a similar manner and stored  
13 in a database.

14

15 It is important to provide a sufficiently long time  
16 window for the radiation pattern created within the  
17 test chamber 4 to create resonant conditions within the  
18 sample (this also applies to other typecasting modes of  
19 operation as shall be described below). The  
20 transmitted radar pulse may be tuned so that the  
21 detected signal indicates that a suitable resonant  
22 radiation conditions have been established.  
23 The second mode of operation relates to the use of  
24 antenna assemblies 200, such as those illustrated in  
25 Fig. 5, being deployed in a transillumination  
26 configuration, without the use of a sample chamber,  
27 such as that illustrated in Fig. 6B, which shows  
28 axially aligned Tx and Rx antenna assemblies 201, 202,  
29 such as those of Figs. 5A - 5N. It will be understood  
30 that transillumination modes of operation do not  
31 necessarily require the Tx and Rx antennas to be  
32 axially aligned. The antennas may be parallel or at an

1 angle to one another on one side of the object etc  
2 under examination, with a reflector placed behind the  
3 object so that the signal from the Tx antenna passes  
4 through the object and is reflected back to the  
5 receiver by the reflector.

6

7 As shown in Fig. 7B, the assemblies are co-axially  
8 aligned to face one another and are placed at an  
9 optimal focusing separation with a test  
10 substance/object located mid-way between the two  
11 sensors in order to achieve a balanced  
12 transillumination effect. Assemblies of this type may  
13 also be used in the arrangements illustrated in Figs 6A  
14 and 6B.

15

16 In this mode, the apparatus provides a means to image  
17 or typecast the internal composition or contents of,  
18 for example, baggage on a conveyor belt. In such an  
19 application, the antenna assemblies 201, 202 are  
20 arranged on either side of the belt to transilluminate  
21 baggage as it moves along the belt. Metallic  
22 reflectors may be further provided below the belt and  
23 around the sides/roof of any surrounding shield.

24

25 The third mode of operation relates to the antenna  
26 assemblies 200 being deployed in a parallel  
27 configuration or at an angle to one another with the  
28 apertures of the Tx and Rx antenna assemblies facing  
29 the same direction and the received signal having been  
30 deviated back towards its source direction (e.g.  
31 reflected or backscattered). Figs. 7A, 8A to 8D, 9 and  
32 10 illustrate examples of this mode of operation. The

1 antenna assemblies may be deployed in a stationary  
2 configuration or one or both of the antenna assemblies  
3 may move relative to the substance/area to be scanned  
4 and/or the substance/area may be moved relative to the  
5 antenna assemblies.

6

7 For example, Fig 7A is a schematic diagram illustrating  
8 the arrangement of the receiving and transmitting  
9 antenna assemblies 201, 202 as described above, in a  
10 GPR application suitable for remotely detecting and/or  
11 imaging and/or typecasting objects and/or substances  
12 located underground. The transmitter assembly 201 and  
13 the receiver assembly 202 may be mounted on suitable  
14 land and/or sea vehicles. For example, Fig 8A  
15 illustrates how the apparatus may be mounted on to the  
16 rear or front of a land vehicle. Alternatively, the  
17 apparatus could be provided to protrude through the  
18 floor or hull of a sea-vehicle such as Fig 8D shows.  
19 Depending on the scale of the antenna assemblies, the  
20 apparatus may be highly portable for applications, such  
21 as Figs 8B and 8C illustrate. Fig 8B shows a portable  
22 device suitable for operation on land whereas Fig 8C  
23 shows a portable device suitable for submerged  
24 operation by a diver.

25

26 Fig. 9 illustrates how a transmitting antenna assembly  
27 201 and a receiving antenna assembly 202 may be  
28 arranged in parallel along a tong 250 forming part of a  
29 submerged moveable platform 280 which can be attached,  
30 for example, to the front of a remotely operated  
31 vehicle 260 suitable for operation on a seabed 270.

32

1 Fig 10 illustrates how a plurality of pairs of arrays  
2 of transmitting antenna assemblies 201 and receiving  
3 antenna assemblies 202 may be arranged on the underside  
4 of pontoon-type supports 300a, 300b for use with a  
5 semi-submersible platform or sea-vehicle. Such a  
6 configuration of the radar apparatus enables sea-bed  
7 sensing, imaging and typecasting of materials for the  
8 oil industry.

9

10 The antenna pairs are spaced along the pontoon,  
11 preferably equidistant from adjacent antenna pairs in  
12 the array. At least one array of receiving antennas is  
13 arranged parallel to the corresponding array of paired  
14 transmitting antennas to enable wide angle reflection  
15 and refraction (WARR) sounding. At least one such  
16 antenna pair array 310a,310b and 320a,320b is provided  
17 on each pontoon, for example, two per pontoon are  
18 illustrated in Fig. 10, to form a total of eight arrays  
19 of antenna assemblies. Using this apparatus, a  
20 variety of large scale structural and compositional  
21 information may be collated from and within the seabed,  
22 for example, the apparatus may be used in such a  
23 "searching mode" to detect subterranean and seabed  
24 features.

25

26 The inventor has detected shipwrecks and the apparatus  
27 may be suitable for the detection of oil and gas  
28 deposits using this apparatus. Features such as  
29 shipwrecks may be buried deep below the seabed.  
30 Although it is possible to detect such features with a  
31 single pair of antenna assemblies over a relatively  
32 small search area, an array of antennas, and preferably

1 a multiple array of antennas can be used. Multiple  
2 arrays could scan many lines in one forward sweep  
3 covering a large search area in a short space of time.

4

5 Furthermore, by allowing the apparatus to remain in  
6 situ and scan a fixed area for a period of time, (i.e.  
7 to "stare" in the surveying mode) it is possible to  
8 record a series of images indicating movement of  
9 substances such as liquids (e.g. oil) and gases (e.g.,  
10 natural gas seepage).

11

12 In the WARR configuration illustrated in Fig 10, the  
13 arrays provided operate in tandem. For example, the  
14 transmitting array 310a will emit signals which are  
15 reflected and recorded by the receiving array 320b, and  
16 the transmitting array 320a will emit signals which are  
17 preferably recorded by the receiving array 310b, etc.  
18 This enables a plurality of lines 330 to be scanned  
19 efficiently along the sea-bed. In the illustrated  
20 example, nine lines 330 can be scanned. In WARR mode  
21 any antenna assembly can be selected as a transmitter  
22 and reflections can be received from any receiving  
23 antenna in any specific order and sampling time to  
24 allow increasing Tx and Rx (see Fig. 10) separation for  
25 triangulation and precision mapping purposes. If this  
26 triangulation procedure is carried out, then a detailed  
27 table of dielectric properties can be produced  
28 including depths, radar velocities, interlayer  
29 thicknesses, interlayer velocities, and interlayer  
30 dielectric constants.

31

1 The sizes of the apertures of the antenna assemblies  
2 may be optimised to suit the path length and the beam  
3 collimation requirements. For deeper sounding and  
4 longer path lengths it may be necessary to vary the  
5 focusing means, for example by fitting narrow apertures  
6 with a range of optional circular slits. These can  
7 then be fitted to the telescopes to provide focusing at  
8 the optimum near/far field ranges. Dielectric lens  
9 attachments such as those illustrated in Figs. 5B to 5D  
10 may also be used for these purposes. The focusing  
11 means selection criteria follows that known in the art  
12 from radar design and selection procedures and are  
13 based on simple geometric, timing and platform speed  
14 considerations.

15  
16 For field operation, typical land vehicles include  
17 ATVs, small robotic platforms, man-portable and/or hand  
18 operated or track or rail mounted for tunnels or mines,  
19 or man portable operated from raised bucket platforms  
20 for scanning vertical wall surfaces of buildings,  
21 tunnels or bridge structures. Typical sea-vehicles  
22 include inflatables, hovercraft, Dory work boats, tug-  
23 boats, hydrographic/seismic-type survey vessels, or  
24 oil-industry semi-submersible platforms with pontoons  
25 suitable for mounting large tube-arrays, or ROVs, or  
26 autonomous underwater vehicles (AUVs), or Jack-Up  
27 Platforms or Drilling Rigs or Stand-Alone Production  
28 Platforms. The antenna assemblies are typically  
29 arranged substantially vertically and are orientated so  
30 that they can stare into the ground/seabed, at depths  
31 capable of resolving oil and gas reservoir structures.  
32 In a specific example for detecting sub-seabed

1 substances, the antenna assemblies 201, 202 may be of  
2 the order of 24m long by 8 inches internal diameter and  
3 may comprise two 12m long by 8 inch (internal diameter)  
4 high quality steel oil tube casings welded to another  
5 two 12m by 8 inch casings to make a pair of large  
6 transmitting and receiving assemblies some 24m long.  
7 Such a geometry for the antenna assemblies is believed  
8 by the inventor to have a natural resonance which  
9 amplifies the radar signal by a factor of 180.

10

11 The apparatus may be further mounted on air/space  
12 vehicles, for example, small helicopters or remotely  
13 powered vehicles (RPVs) such as model aircraft, or  
14 balloons, blimps or piloted auto-gyros. Spaceborne  
15 platforms may be used for subsurface geological  
16 investigations of moons, comets and/or other planets.

17

18 The selection of appropriate antenna configurations and  
19 aperture sizes enables different scales to be resolved,  
20 for example, objects/substances which are underground  
21 or underwater (see for example, Figs 8C, 8D, 9 and 10).

22

23 Fig. 11A illustrates a further embodiment of the  
24 invention with a Tx antenna assembly 201 and an Rx  
25 antenna assembly mounted on a conventional optical  
26 microscope 700, for the purpose of examining, for  
27 example, biological samples mounted on microscope  
28 slides 702. The Rx assembly 202 is mounted in a socket  
29 of the microscope which would normally be occupied by  
30 an ocular (eyepiece). The end of the Rx assembly 202  
31 may be suitably configured to fit this existing socket.  
32 The Tx assembly 201 in this example is mounted in a

1       socket or the like which would normally receive a light  
2       source for illuminating the slide 712. If the  
3       microscope is of the binocular type, the other ocular  
4       may be used for visual observation of the slide and for  
5       focussing the microscope. The transmitted signal from  
6       the Tx assembly 201 follows the normal optical path  
7       through the microscope to the Rx assembly 202. That  
8       is, the Tx and Rx assemblies 201, 202 are arranged for  
9       transillumination of the slide 702. Alternatively, the  
10      Tx and Rx assemblies could be mounted side by side in  
11      the ocular sockets of a binocular microscope, for  
12      reflection mode operation. In this way, a variety of  
13      different types of optical microscope may be adapted  
14      for operation as "radar microscopes" and may be used  
15      for imaging and/or typecasting of biological samples or  
16      the like in a variety of applications including medical  
17      diagnosis. For scanning purposes, the slide 702 may be  
18      translated relative to the Tx and Rx assemblies by  
19      using the conventional movable slide stage of the  
20      microscope.

21

22      For precision mapping applications of the invention, it  
23      is necessary to employ calibrated antenna assemblies,  
24      preferably of the type illustrated in Figs. 5E to 5N,  
25      whose relative separation can be varied for optimised  
26      triangulation of range distance. Preferably, the  
27      transmitting, Tx, and receiving antennas, Rx, can be  
28      rotated about their longitudinal axes through 0 - 360°  
29      relative to one another to enable variable polarisation  
30      of signals, so as to optimise coherent image  
31      reflections of targets and interfaces of interest.

32

1 The triangulation factor is important for many  
2 applications of the invention. The polarisation factor  
3 is of greatest significance for close range inspection  
4 of structures such as pipes or concrete sections.  
5 Changing the polarisation, by a factor of 90° for  
6 example, can enable the collection of multivariate  
7 image-data sets along each scan line. This often  
8 assists the classification of the medium and provides  
9 co-ordinates of point targets or structures in the  
10 medium being investigated.

11

12 The antennas can typically be oriented in two ways:  
13 plane polarised (PP or Plane Mode) or cross polarised  
14 (CP, 90° mode) where Tx is oriented at 90° to Rx or vice  
15 versa. Therefore, at any given frequency, two  
16 different sets of spectral reflection data (or digital  
17 image bands) can be collected. The design of suitable  
18 spatial frequency filters and the use of principal  
19 components analysis (PCA) for multivariate image  
20 mapping of such complex multi-spectral and multi-  
21 polarised image datasets can greatly assist in  
22 identifying, for example, engineering structures of  
23 interest for precision mapping and classification.

24

25 Consideration must also be given to the spatial (X,Y,Z)  
26 co-ordinates of both the transmitting and receiving  
27 antennas. This means that the area to be investigated  
28 should be precisely surveyed to build up a concise  
29 topographic survey database of co-ordinates for each  
30 line scanned. In cases where the scanning lines are  
31 non-linear, it is important to track the antennas on

1    their scanning platform during the data collection  
2    phase.

3

4    This situation may arise, for example, when scanning  
5    the irregular topographic features of a biopsy  
6    specimen, as the antennas will be mounted on a simple  
7    biopsy scanning platform (BSP) and not in direct  
8    contact with the surgical specimen. With a fixed  
9    antenna configuration on a BSP, where the tissue is  
10   irregular, the air gap between the antenna and the  
11   specimen will vary considerably. Therefore, it is  
12   important to simultaneously track the antennas during  
13   the scanning phase so that the true subject datum plane  
14   is known and can be related to precise X, Y and Z co-  
15   ordinates of the subject being investigated.

16

17   To achieve coherent imaging, it is important that the  
18   optimum scan configuration of the antennas is selected.  
19   Essentially, this is the fixed separation distance  
20   between the Tx and Rx antennas mounted on the scanning  
21   rig or BSP. For imaging of deeper structures the  
22   antennas have to be fixed with a wider separation  
23   distance. Again, for focussing through lower  
24   dielectric materials or deeper organs in the body, the  
25   antennas should be moved further apart. To acquire  
26   accurate depth data it is important to triangulate  
27   every scan line, in the body's sub-surface domain.  
28   This can be achieved by overlapping scan legs from the  
29   start of scan position (SOS) to the end of scan  
30   position (EOS). This type of scanning is commonly  
31   referred to as a WARR scan (wide angle reflection and  
32   refraction, as illustrated in Fig. 11A which shows a

1 fixed Tx antenna assembly 201, and a movable Rx antenna  
2 assembly 202 moving progressively away from the Tx  
3 antenna 201 in the direction of the arrows, relative to  
4 a subject 704, such as a cancer tumour within a body).  
5 This can be achieved by automatic sensor array digital  
6 switching, managed by software control.

7

8 As the scanning rig moves along the scan line, the Rx  
9 antenna assembly captures each new reflection and plots  
10 the returns alongside the previously scanned returns.  
11 This process integrates reflection traces and  
12 eventually a comprehensive image of the subject 704 is  
13 obtained. To compose a coherent image, the system  
14 processes the response reflections from the objects  
15 examined. These are automatically enhanced to optimise  
16 desired targets and layered boundary reflections may be  
17 classified.

18

19 The images may also be suitably scaled by software,  
20 with re-sampling and auto-zoom features enabling 2-D  
21 and 3-D visualisation of point targets and boundary  
22 interfaces, displayed in real time. These features,  
23 together with the use of classified colour palettes,  
24 can discriminate the textural classes or surface  
25 roughness (for example) of a wide range of materials.  
26 A typical breast carcinoma may consist of six distinct  
27 tissue layers, with layer thicknesses measured in  
28 micrometers (e.g.: 76, 76, 152, 202, 88, 77), each with  
29 a different dielectric constant.

30

31 Further analysis of the image may display dielectric  
32 tables showing mean inter-layer thicknesses, depths,

1 propagation velocities and dielectric constants. These  
2 tables may also include RMS error computations in two  
3 way travel time measured in nanoseconds (NS) and depth  
4 in metres (m) for each stratigraphic boundary.

5

6 The preferred signal processing software performs real-  
7 time de-convolution of the transmit pulse to allow true  
8 conformal mapping of object shapes. For example,  
9 conventional GPR reflections from circular or  
10 elliptical section structures such as pipes occur as  
11 parabolic echoes from the top and bottom of the pipe  
12 reflecting surfaces, whereas mapping in the manner  
13 described above will display the structures in their  
14 true circular or elliptical shapes.

15

16 From the resultant images, materials can be  
17 spectroscopically identified and classified (as  
18 described further below), provided they have been  
19 previously typecasted and their spectral  
20 characteristics logged in the reference database. If  
21 this is the case, classification is possible in near-  
22 real-time; that is, within a few micro-seconds of data  
23 capture. Depths can be automatically calculated by the  
24 system computer after the WARR results have been  
25 implemented. Thus, it is simply a matter of reading  
26 the depth of a required target position from the scaled  
27 image.

28

29 Fig. 12 is a table summarising system specifications  
30 for a variety of operational modes of systems embodying  
31 the invention. Fifteen modes of operation A1 - A5, B1  
32 - B5 and C1 - C5 are indicated, exemplifying the broad

range of applications of the invention. Modes A1 - A5 are close range/near field (small scale) modes for a range of increasing distances between the Tx antenna and the subject, suitable for applications such as biological and medical imaging. Modes B1 - B5 are near to medium range (medium scale) modes, again for a range of increasing distances, suitable for typical GPR applications with relatively shallow penetration. Modes C1 - C5 are long range (large scale) modes, suitable for geological/geophysical applications, particularly in the oil industry, for relatively deep subsea/subsurface penetration. The various modes would typically use substantially the same computer, pulse generator and radar control apparatus, with different Tx and Rx antenna assemblies, these preferably being of the types illustrated in Figs. 5A to 5N, smaller assemblies (e.g. about 200 mm to 300 mm in length) being used for modes A1 to A5, intermediate size assemblies being used for modes B1 to B5, and larger size assemblies (e.g. up to about 24 m in length) being used for modes C1 to C5.

The resolution time and resolution space (columns 2 and 3) indicate the resolution which may be obtained using each mode. Values given are for salt water and may be converted for other media with different dielectric properties. Column 4 indicates suitable values of the Pulse Repetition Frequency (PRF) for each mode, being higher for close range applications and lower for longer range applications. Column 4 indicates suitable Pulse Width (Pw) values for the various modes, these being shorter for close range modes and longer for long

1 range modes. For each of modes A1 - A5, suitable  
2 values are in the range 10 - 100 ps (picoseconds) i.e.  
3 0.01 to 0.1 ns (nanoseconds); for each of modes B1 -  
4 B5, suitable values are in the range 1 - 10 ns; for  
5 each of modes C1 - C5, suitable values are in the range  
6 10 to 25 ns. The table of Fig. 12 utilises Pw values  
7 of 0.1 ns for modes A1 - A5, 1 ns for modes B1 - B5 and  
8 10 ns for modes C1 - C5. Column 6 indicates the Time  
9 Range (TR) in the received signal produced by each  
10 transmitted pulse which will contain data of interest  
11 at the relevant distance and scale. The Time Range  
12 would normally begin with the first peak of the  
13 received signal. The Time Range is shorter for close  
14 range/small scale applications and longer for long  
15 range/large scale applications.

16

17 Columns 6 and 7 indicate the preferred frequency ranges  
18 (Fmin to Fmax) of the transmitted pulse for each mode,  
19 being higher for close range/small scale applications  
20 requiring little penetration and high resolution and  
21 lower for long range/large scale applications requiring  
22 deep penetration and lower resolution. The frequency  
23 range is determined by the radar system as a whole,  
24 including the characteristics of the TX and Rx  
25 antennas. Columns 9 to 11 indicate suitable values of  
26 pulses-per-trace (Ptr), scan rate (SR, traces-per-  
27 second) and Sdelay (1/SR) for the purposes of sampling,  
28 storing and displaying digitised data.

29

30 The total frequency range of the radar systems is  
31 indicated as 1 MHz to 10 GHz, which covers an  
32 exceptionally wide range of frequencies. This range is

1 suited for the various imaging and typecasting  
2 operations of the apparatus at various distances and  
3 scales. For each of the fifteen modes, the sampling  
4 rate ( $F_s$ ) most preferably equals two times the maximum  
5 frequency ( $F_{max}$ ) as indicated in column 7 of Fig. 12B.  
6 The sampling rate is determined by the difference in  
7 time delays from pulse to pulse. For all modes of  
8 operation, the sampling rate preferably falls in the  
9 range  $F_{max}/4$  to  $4F_{max}$ . The sampling time,  $T_s$  (column  
10 12), is different from the sampling rate, being the  
11 time during which the analogue signal is sampled before  
12 being digitised, corresponding to the time represented  
13 by one pixel in the y-direction. Preferably, on  
14 average, the sampling time  $T_s$  is  $1/(2F_{max})$ . It should  
15 be at least  $1/F_{max}$  but for fast scanning it is  
16 recommended to be  $1/(4F_{max})$  which equates to 0.25 ns  
17 where  $F_{max} = 1$  GHz.

18  
19 It is important that the analogue input signal is  
20 filtered before sampling to avoid aliasing. This is  
21 partially accomplished by the sampler 516 (Fig. 2)  
22 which averages the signal over the sampling time. The  
23 lower frequency range is limited by the Tx and Rx  
24 antennas, the time window and a low frequency component  
25 from the radar. The lowest frequency that can be  
26 resolved is the reciprocal of the time from time zero  
27 to the end of the trace. For example, consider mode A5  
28 of Fig. 12. In this case, the 25 ns time range (column  
29 6) will have a minimum frequency of  $(25\text{ ns})^{-1}$ , i.e. 40  
30 MHz. This is an absolute minimum value. For practical  
31 purposes, a higher value (100 MHz in Fig. 12) is  
32 preferably selected.

1  
2 Modes A1 to A5 are intended for close range or near  
3 field imaging and typecasting such as in medical and  
4 biological applications. The recommended frequency  
5 ranges for these modes of operation is from a minimum  
6 frequency ( $F_{min}$ ) in the range 100 MHz (A5) to 1 GHz  
7 (A1) to a maximum frequency in the range 1 GHz (A5) to  
8 10 GHz (A1). For these frequency ranges, the sampling  
9 rate ( $F_s$ ) is determined by the difference in time  
10 delays from pulse to pulse. As noted above, the  
11 criterion for selecting  $F_s$  is that it should be at  
12 least two times  $F_{max}$  for most applications, or  
13 preferably four times  $F_{max}$  for some specific  
14 applications such as fast scanning. The preferred  
15 overall range for all modes is  $F_{max}/4$  to  $4F_{max}$ .  
16

17 The pulse repetition frequency (PRF) is the rate at  
18 which pulses are emitted from the transmitter. For  
19 close range (focussed near field imaging) medical and  
20 biological applications, PRF should be at least 64 kHz  
21 for combined imaging and typecasting applications, but  
22 the preferred maximum value is 100 kHz.  
23

24 The number of pulses per trace (Ptr, column 9, Fig.  
25 12B) is important for efficient operation of the  
26 apparatus. The preferred maximum Ptr for modes A1 -  
27 A5, to cover a wide range of diagnostic medical,  
28 biological and biochemical applications, is 100 pulses  
29 per trace. The maximum time window, TR, is a function  
30 Ptr and Ts, as follows:  $TR = (Ptr \times Ts)$ . Accordingly,  
31 in mode A3 operation:  $Ts = 1/2F_{max}$ ; i.e.  $Ts = 10^{-10} =$   
32 0.1 ns;  $TR = (100 \times 0.1) \text{ ns} = 10 \text{ ns}$ .

1

2 There is a trade off between parameters for optimum  
3 imaging and typecasting performance. Higher values of  
4 Fmax always give better results in terms of resolution  
5 etc. but at the expense of penetration, data processing  
6 etc.

7

8 Modes B1 - B5 relate to near range to medium range  
9 (focused subsurface imaging) general ground penetrating  
10 radar (GPR) applications. For these modes, the  
11 preferred value of PRF is also 100 kHz. The optimum  
12 range of Ptr to cover this range of applications is  
13 4000 to 9600 pulses per trace.

14

15 Modes C1 - C5 relate to medium range to long range (far  
16 field) applications. For many far field geological  
17 applications, a most appropriate time range would be of  
18 the order of 20000 to 80000 ns. For deep geological  
19 applications (i.e. shallow seismic to deep seismic type  
20 depths up to thousands of metres), the time ranges of  
21 the order of 160000 to 250000 ns may be selected.

22

23 Stacking the pulse ( $S_t$ ) is a common method of enhancing  
24 the imaged products in conventional geophysical or  
25 seismic imaging. This technique can be applied in the  
26 present system at the time of data collection (through  
27 digital control) or it can be carried out externally by  
28 post-processing of the collected radar imagery. In the  
29 latter case, then the data collection rate is  
30 preferably increased.

31

1     The scanning rate (SR) equals the number of traces (or  
2     scans) per second. The maximum value of SR equals PRF  
3     divided by the product of Ptr and St. For example  
4     (mode A1), where Ptr equals 40, PRF equals 100 kHz and  
5     St equals 1 (no stacking), then  $SR = (100 \times 10^3) / (40 \times$   
6     1) = 2500 scans per second.

7

8     With reference to the setting up of the radar system  
9     for operational use, the time zero ( $T_0$ ) position is of  
10    particular importance.  $T_0$  will generally be selected as  
11    appropriate for a particular application, to ensure  
12    that all of the relevant received signal data is  
13    retrieved. In general terms  $T_0$  is the time at which the  
14    transmitted pulse is received by the shortest  
15    transmission path between the transmitter and the  
16    receiver (the "direct wave", e.g. transmitted through  
17    air in an air medium or through water in a water  
18    medium). The required  $T_0$  position is not actually the  
19    zero point on the time scale because the pulse has  
20    travelled from the transmitter unit to the receiver  
21    unit, so the  $T_0$  position actually corresponds to the  
22    distance between the transmitter antenna and the  
23    receiver antenna divided by the speed of the pulse.  
24    This factor is important for obtaining accurate depth  
25    measurements through materials, especially those with  
26    multivariate dielectric constants and inter-layer  
27    velocities. It is important that the  $T_0$  position is  
28    included in the time window range (TR, column 6, Fig.  
29    12) or in the displayed image on the visual display  
30    unit of the computer. The direct wave received pulse  
31    can be used to de-convolve the image. This will  
32    generally produce a less cluttered image; i.e. objects

1 such as circular section pipes will appear circular  
2 rather than as parabolic reflections of the top and  
3 bottom of the pipe.

4

5 The position of  $T_0$  in the image depends on the various  
6 delays in the radar system and is preferably set up  
7 when the radar is first switched on, before any other  
8 settings are altered.

9

10 The foregoing discussion, referring to Fig. 12 of the  
11 drawings, applies particularly to transillumination and  
12 reflection modes of operation.

13

14 To set up appropriate conditions in order to typecast  
15 material in chamber mode operation (as illustrated in  
16 Fig. 6A), the following technique may be used when  
17 using a conventional GPR radar set (or equivalent) as  
18 the pulse generator. To provide optimum control during  
19 the set up procedure, the best method found by the  
20 inventor is to switch off the Automatic Gain Control  
21 and the Time Varying Gain Control of the pulse  
22 generator 21 (Fig. 1). A reasonable received signal  
23 bandwidth is then established by suitable selection of  
24 the cut-off frequencies of a high-pass filter and low-  
25 pass filter; for example, between 40 Hz and 3.2 kHz.

26

27 A large enough time window is selected for sampling to  
28 allow a sufficient number of resonant ringing  
29 reflections through the scanned substance/object to  
30 have occurred to enable significant spectral  
31 relationships for each sampled substance to be  
32 established. The inventor has found that in the case

1 where a 25ml sample was placed in the chamber portion  
2 4a (Fig. 6A), and 20ml of air was left in the sample  
3 chamber portion 4b, that a suitable time window was  
4 approximately 16ns. Increasing the minimum time window  
5 to, for example, 25ns, further enables sufficient  
6 resonant effects to be established and tested. The  
7 sampling interval, or scan rate, is selected to allow a  
8 sufficient pulse dwell time to enable resonance through  
9 the sampled substance to be optimised. In this  
10 example, sampling was optimised with a sampling  
11 interval of 100ms (10 scans per second) to ensure that  
12 consistent results were obtained on repetitive tests.  
13 In general, as a lower limit, the sampling interval  
14 should not be less than 50ms; i.e. the scan rate should  
15 not exceed 20 scans per second. However, for certain  
16 fast scanning applications, it is possible to scan at  
17 200 scans per second and it is also possible for  
18 typecasting to be performed at this rate.

19

20 The data obtained using the apparatus, systems and  
21 methods as described thus far may be used for a variety  
22 of purposes, including imaging, mapping, dimensional  
23 measurement, and typecasting (identification of  
24 materials etc.).

25

26 The time domain data as received by the receiver may be  
27 processed for imaging/mapping/measurement purposes  
28 using well known techniques employed in conventional  
29 GPR and other imaging/mapping applications, which will  
30 not be described herein.

31

1 The time domain data may be transformed into frequency  
2 domain data, by means of Fourier Transform techniques  
3 (especially FFT). This provides an energy/frequency  
4 spectrum which, in accordance with one aspect of the  
5 invention, may be used as a unique signature to  
6 identify (typecast) the material which produced the  
7 spectrum. In accordance with this aspect of the  
8 invention, the energy/frequency spectrum is analysed  
9 using any of a variety of well known statistical  
10 analysis methods (such as principal components  
11 analysis, maximum likelihood classification or  
12 multivariate classification) or combinations of such  
13 methods, in order to obtain a parameter set. A  
14 reference database of known materials is established,  
15 comprising the original time domain data, and/or the  
16 transformed data, and/or the parameter set obtained  
17 therefrom, and an unknown material can thereafter be  
18 identified by comparing its parameter set, also  
19 obtained by means of the apparatus, systems and methods  
20 of the present invention, with those in the reference  
21 database. The statistical analysis of the  
22 energy/frequency spectrum may be performed either by  
23 frequency classification (using energy bins) or by  
24 energy classification (using frequency bins).

25  
26 Conventional analytical methods may also be applied to  
27 the data for classification purposes, such as time  
28 domain reflectrometry techniques, velocity distribution  
29 analysis or the like, as used in conventional  
30 geophysical applications for determining dielectric  
31 properties.

32

1       The computer forming part of the radar system in  
2       accordance with the invention may be programmed to  
3       perform these functions.  
4  
5       By use of the invention, it is possible to classify and  
6       map oil, water and gas reserves deep underground  
7       without the need for drilling. By staring deep  
8       underground, it is possible to monitor oil, water and  
9       gas movements and to classify oils already typecast and  
10      held in reference databases of oil types etc.  
11  
12      Other applications include the detection of explosives,  
13      contraband substances, and in particular narcotics, as  
14      well as the typecasting of rock, soil, sediment and ice  
15      cores, and biological/medical imaging and diagnosis.  
16  
17      The preferred antenna assemblies of the present  
18      invention (Figs. 5A to 5N) are believed to operate in a  
19      manner analogous to a laser, except that radio waves  
20      are resonated in a highly dielectric medium and with a  
21      carefully selected dielectric medium and with a  
22      carefully selected dielectric lens aperture with  
23      concentric circular focusing slits. With a 3mm  
24      aperture, it is possible to focus the beam from 3mm  
25      outside the central aperture to infinity, like a pin-  
26      hole camera.  
27  
28      An example image obtained by means of the invention is  
29      shown in Fig 11. The image represents a scan of a  
30      short cylindrical core of gold in a quartzite seam  
31      indicated at A. The width of this short scanned

1 portion is 280mm and the diameter of the gold core is  
2 approximately 40mm.

3

4 The vertical dimension reflects the time domain and the  
5 horizontal scale has been rectified to represent the  
6 length of the core scanned by the moving antenna pair.

7 The top of the image is 0ns. Further time delays  
8 represent signals reflected from deeper within the  
9 sample core. Looking down through the core reflections  
10 are recorded to about 5.4ns. Two further harmonic  
11 reflections are provided which provide information on  
12 surface roughness of the core and arise from too much  
13 initial power being used to generate the radar pulse.

14 The first reflection lies from approximately 7ns to  
15 13ns in time range and the second multiple surface  
16 reflection shows an enlarged portion of the core from  
17 17ns to 25ns, the limit of the 25ns time window  
18 selected.

19

20 The selection of appropriate circular slit apertures  
21 224,225 and ring spacings 226 and the choice of  
22 dielectric filler 228 which launches the wave enables  
23 the internal structure of the core to be perceived. If  
24 the anode length is proportional to the tube length as  
25 previously described, for example  $1/\alpha$  or in this case  
26  $1/10$ th of the total internal telescope tube 227 length,  
27 then the time delay of the radar beam (i.e., the time  
28 from emission to detection) is multiplied by the  
29 reciprocal  $\alpha$  of the fraction  $1/\alpha$ ; i.e., the actual time  
30 delay  $T_D = \alpha \times$  the expected time delay  $T_E$ , where  $T_E$  is  
31 as is given in conventional ground penetrating radar

1 (GPR) formulae. Using the conventional GPR Range  
2 Formulae, this 40 mm core of quartzite with a mean  
3 dielectric constant ( $\epsilon_R = 5$ ) should have produced an  
4 equivalent time range length on the image of 0.54ns,  
5 but the 10:1 factor stretched the time range because  
6 the beam was slowed down in the telescope and this  
7 resulted in a time range image spanning 5.4ns. This is  
8 considered by the inventor to be a tube geometry and  
9 dielectric lens effect, and will assist in the near  
10 range focusing of radio-wave cameras and microscopes as  
11 well as radio-wave telescopes for mapping deep below  
12 ground level or the sea-bed.

13

14 The above description relates to particular embodiments  
15 of the invention. In general, the values or ranges of  
16 values indicated for various parameters may all vary  
17 and may be dependent on the particular application of  
18 the invention.

19

20 Furthermore, if the dielectric properties of the  
21 cladding material surrounding the antenna of the  
22 telescopes vary under given conditions, for example if  
23 the dielectric constant is thermally dependent, such as  
24 is the case with barium titanate, then it is possible  
25 to detect such conditions by using the invention to  
26 "stare" at the substance and monitoring the change in  
27 the received spectral data. This could enable the  
28 thermal conditions of subterranean  
29 structures/substances/objects to be determined. Other  
30 dielectrics of interest include lead zirconate titanate  
31 (PZT) and ammonium dihydrogen phosphate.

1  
2 For the removal of doubt, wherever specific reference  
3 has been made to a "substance", "sample" or the like,  
4 the term may be taken to include other objects, liquids  
5 and powders as well as larger or smaller scale  
6 geological, marine or biological features etc. The  
7 term "subject" as used herein means any such substance,  
8 sample, object, feature etc. to be imaged, detected or  
9 analysed by means of the invention.

10  
11 It will be understood that for certain applications of  
12 the invention, the transmitting and receiving antennas,  
13 antenna arrays or antenna assemblies may be combined in  
14 transceiver arrays or assemblies.

15  
16 While several embodiments of the present invention have  
17 been described and illustrated, it will be apparent to  
18 those skilled in the art once given this disclosure  
19 that various modifications, changes, improvements and  
20 variations may be made without departing from the  
21 spirit or scope of this invention.

1     Claims

2

3     1. A radar antenna assembly for use as a transmitter,  
4 receiver or transceiver comprising:

5                 a tubular casing having a radar-reflective inner  
6 surface and having a first end, a second end and a  
7 longitudinal axis;

8                 a radar-reflective reflector closing said first  
9 end;

10                an aperture disposed at said second end;

11                at least one elongate antenna element extending  
12 substantially parallel to said longitudinal axis from  
13 said reflector towards said second end; and

14                dielectric material substantially filling the  
15 interior volume of said tubular casing.

16

17     2. A radar antenna assembly as claimed in Claim 1,  
18 further including focussing means at said second end.

19

20     3. A radar antenna assembly as claimed in Claim 2,  
21 wherein said focussing means includes a plurality of  
22 concentric slit ring apertures located at said second  
23 end.

24

25     4. A radar antenna assembly as claimed in Claim 2 or  
26 Claim 3, wherein said focussing means includes at least  
27 one dielectric lens element located at said second end.

28

29     5. A radar antenna assembly as claimed in Claim 4,  
30 wherein said dielectric lens element comprises a planar  
31 lens element.

32

1     6. A radar antenna assembly as claimed in Claim 4,  
2     wherein said dielectric lens element comprises a plano-  
3     concave lens element.

4

5     7. A radar antenna assembly as claimed in Claim 4,  
6     wherein said dielectric lens element comprises a plano-  
7     convex lens element.

8

9     8. A radar antenna assembly as claimed in any  
10    preceding Claim, wherein said tubular casing has an  
11    inner diameter  $D_T$  of which is an integer multiple of the  
12    diameter  $D_A$  of said at least one antenna element.

13

14    9. A radar antenna assembly as claimed in any  
15    preceding Claim, wherein said tubular casing has an  
16    interior length  $L_T$  which is an integer multiple of the  
17    length  $L_A$  of said at least one antenna element.

18

19    10. A radar antenna assembly as claimed in any  
20    preceding Claim, wherein an interior surface of said  
21    tubular casing comprises an antenna cathode and said  
22    elongate antenna element comprises an antenna anode.

23

24    11. A radar antenna assembly as claimed in Claim 10,  
25    wherein said elongate antenna element extends along  
26    said longitudinal axis.

27

28    12. A radar antenna assembly as claimed in any one of  
29    Claims 1 to 9, including at least two of said elongate  
30    antenna elements, at least one of which comprises an  
31    antenna cathode and at least one of which comprises an  
32    antenna anode.

1  
2     13. A radar antenna assembly as claimed in Claim 12,  
3     wherein said elongate antenna elements are disposed  
4     symmetrically about the longitudinal axis of the  
5     tubular casing.

6  
7     14. A radar antenna assembly as claimed in Claim 13,  
8     wherein said elongate antenna elements have  
9     substantially equal lengths and diameters.

10  
11     15. A radar antenna assembly as claimed in Claim 14,  
12     wherein the interior diameter  $D_T$  of the tubular casing  
13     is an integer multiple of the diameter  $D_A$  of said  
14     elongate antenna elements and of the spacing between  
15     adjacent pairs of said elongate antenna elements.

16  
17     16. A radar antenna assembly as claimed in any  
18     preceding Claim, wherein said dielectric material is a  
19     liquid.

20  
21     17. A radar antenna assembly as claimed in any  
22     preceding Claim, wherein said dielectric material is a  
23     solid.

24  
25     18. A radar antenna assembly as claimed in any  
26     preceding Claim, wherein said dielectric material is a  
27     powdered solid packed into the interior of said tubular  
28     casing.

29  
30     19. A radar antenna assembly comprising a closed  
31     chamber adapted to contain a sample of material, said  
32     chamber including four substantially triangular side

1       walls together defining an open-based pyramidal  
2       structure, said assembly including transmitter antenna  
3       elements disposed on interior surfaces of a first  
4       opposed pair of said triangular side walls and receiver  
5       antenna elements disposed on interior surfaces of a  
6       second opposed pair of said triangular side walls.

7

8       20. A radar antenna assembly as claimed in Claim 19,  
9       wherein said antenna elements comprise bowtie dipole  
10      antennas with respective cathode and anode elements  
11      disposed on said opposed pairs of said triangular side  
12      walls.

13

14      21. A radar antenna apparatus as claimed in Claim 19  
15      or Claim 20, wherein the base of said pyramidal  
16      structure is closed by a generally planar base wall,  
17      said chamber comprising the interior volume of said  
18      pyramidal structure.

19

20      22. A radar antenna assembly as claimed in Claim 19 or  
21      Claim 20, wherein said chamber comprises a closed  
22      volume communicating with the open base of said  
23      pyramidal structure.

24

25      23. A radar system comprising pulsed signal generating  
26      means, transmitter antenna means, receiver antenna  
27      means, control means for controlling the operation of  
28      said pulsed signal generating means, analog-digital  
29      converter means for digitising signals received by said  
30      receiver antenna means, and data storage means for  
31      storing said digitised signals, wherein said  
32      transmitter antenna means and receiver antenna means

1 comprise at least one radar antenna assembly as claimed  
2 in any one of Claims 1 to 22.

3

4 24. A radar system as claimed in Claim 23, wherein  
5 said transmitter antenna means comprises at least one  
6 transmitter radar antenna assembly as claimed in any  
7 one of Claims 1 to 18, and said receiver antenna means  
8 comprises at least one receiver radar antenna assembly  
9 as claimed in any one of Claims 1 to 19.

10

11 25. A radar system as claimed in Claim 24, wherein  
12 said transmitter and receiver antenna assemblies are  
13 disposed so as to transilluminate a subject.

14

15 26. A radar system as claimed in Claim 24, wherein  
16 said transmitter and receiver antenna assemblies are  
17 disposed so as to be co-axially aligned on opposite  
18 sides of a subject.

19

20 27. A radar system as claimed in any one of Claims 24  
21 to 26, wherein said transmitter and receiver antenna  
22 assemblies are connected to a closed sample chamber  
23 adapted to enclose a subject.

24

25 28. A radar system as claimed in Claim 24, wherein  
26 said transmitter and receiver antenna assemblies are  
27 disposed such that said receiver antenna assembly  
28 receives a signal transmitted by said transmitter  
29 antenna assembly and reflected from a subject.

30

31 29. A radar system as claimed in Claim 28, wherein  
32 said transmitter and receiver antenna assemblies are

1       arranged such that their longitudinal axes are  
2       substantially parallel to one another with their second  
3       ends facing in the same direction.

4

5       30. A radar system as claimed in Claim 28 or 29,  
6       wherein said system is adapted to be portable.

7

8       31. A radar system as claimed in Claim 28 or Claim 29,  
9       wherein said system is adapted to be carried by a land  
10      vehicle.

11

12      32. A radar system as claimed in Claim 28 or Claim 29,  
13      wherein said system is adapted to be carried by a  
14      water-borne vessel.

15

16      33. A radar system as claimed in Claim 28 or Claim 29,  
17      wherein said system is adapted to be carried by a  
18      submersible vehicle.

19

20      34. A radar system as claimed in Claim 28 or Claim 29,  
21      wherein said system is adapted to be carried by an  
22      airborne vehicle.

23

24      35. A radar system as claimed in Claim 28 or 29,  
25      wherein said system is adapted to be carried by a space  
26      vehicle.

27

28      36. A radar system as claimed in Claim 28 or Claim 29,  
29      wherein the position of said transmitter antenna  
30      assembly is fixed relative to said receiver antenna  
31      assembly.

32

1       37. A radar system as claimed in Claim 28 or Claim 29,  
2       wherein at least one of said transmitter antenna  
3       assembly and said second antenna assembly is adapted to  
4       be movable relative to a subject.

5

6       38. A radar system as claimed in Claim 28 or Claim 29  
7       in which one of said transmitter and receiver antenna  
8       assemblies is adapted to be movable relative to the  
9       other.

10

11      39. A radar system as claimed in any one of Claims 28  
12     to 38, including a plurality of transmitter antenna  
13     assemblies.

14

15      40. A radar system as claimed in any one of Claims 28  
16     to 39, including a plurality of receiver antenna  
17     assemblies.

18

19      41. A radar system as claimed in any one of Claims 28  
20     to 40, for use with close range subjects, in which said  
21     control means is adapted to control said pulsed signal  
22     generating means so as to generate pulses with a pulse  
23     repetition frequency of the order of 100 kHz.

24

25      42. A radar system as claimed in any one of Claims 28  
26     to 41, for use with close range subjects, in which said  
27     control means is adapted to control said pulsed signal  
28     generating means so as to generate pulses with a pulse  
29     width in the range 0.01 to 0.1 nanoseconds.

30

1       43. A radar system as claimed in any one of Claims 28  
2       to 42, for use with close range subjects, adapted to  
3       capture data in a time range of 2 to 25 nanoseconds.

4

5       44. A radar system as claimed in any one of Claims 28  
6       to 43, for use with close range subjects, adapted to  
7       transmit pulses with a minimum frequency in the range  
8       100 to 1000 MHz and with a maximum frequency in the  
9       range 1000 to 10000 MHz.

10

11      45. A radar system as claimed in any one of Claims 28  
12      to 40, for use with close to medium range subjects, in  
13      which said control means is adapted to control said  
14      pulsed signal generating means so as to generate pulses  
15      with a pulse repetition frequency of the order of 25 to  
16      100 kHz.

17

18      46. A radar system as claimed in any one of Claims 28  
19      to 40 or 45, for use with close to medium range  
20      subjects, in which said control means is adapted to  
21      control said pulsed signal generating means so as to  
22      generate pulses with a pulse width in the range 1 to 10  
23      nanoseconds.

24

25      47. A radar system as claimed in any one of Claims 28  
26      to 40, or 45 or 46, for use with close to medium range  
27      subjects, adapted to capture data in a time range of  
28      2000 to 10000 nanoseconds.

29

30      48. A radar system as claimed in any one of Claims 28  
31      to 40, or 45 to 47, for use with close to medium range  
32      subjects, adapted to transmit pulses with a minimum

1 frequency in the range 12.5 to 125 MHz and with a  
2 maximum frequency in the range 200 to 2000 MHz.

3

4 49. A radar system as claimed in any one of Claims 28  
5 to 40, for use with long range subjects, in which said  
6 control means is adapted to control said pulsed signal  
7 generating means so as to generate pulses with a pulse  
8 repetition frequency of the order of 3.125 to 50 kHz.

9

10 50. A radar system as claimed in any one of Claims 28  
11 to 40 or 49, for use with long range subjects, in which  
12 said control means is adapted to control said pulsed  
13 signal generating means so as to generate pulses with a  
14 pulse width in the range 10 to 25 nanoseconds.

15

16 51. A radar system as claimed in any one of Claims 28  
17 to 40, or 49 or 50, for use with long range subjects,  
18 adapted to capture data in a time range of 20000 to  
19 250000 nanoseconds.

20

21 52. A radar system as claimed in any one of Claims 28  
22 to 40, or 49 to 51, for use with long range subjects,  
23 adapted to transmit pulses with a minimum frequency in  
24 the range 1 to 12.5 MHz and with a maximum frequency in  
25 the range 12.5 to 200 MHz.

26

27 53. A radar system as claimed in any one of Claims 23  
28 to 52, further including data processing means for  
29 processing said digitised signals.

30

31 54. A radar system as claimed in Claim 53, wherein  
32 said data processing means is adapted to process said

1 digitised signals for the purposes of at least one of  
2 imaging, measuring, mapping, detecting, identifying and  
3 typecasting said subject.

4

5 55. A method of typecasting a subject comprising the  
6 steps of:

7 irradiating the subject with a pulsed, broad band  
8 radar frequency signal transmitted by at least one  
9 transmitter antenna;

10 detecting a return signal following interaction of  
11 said transmitted signal with said subject, using at  
12 least one receiver antenna;

13 calculating an energy-frequency spectrum of said  
14 return signal; and

15 analysing said energy-frequency spectrum to obtain  
16 a characteristic energy-frequency signature of said  
17 subject.

18

19 56. A method as claimed in Claim 55, wherein said step  
20 of analysing said energy-frequency spectrum comprises  
21 performing a statistical analysis of said energy  
22 frequency spectrum.

23

24 57. A method as claimed in Claim 56, wherein said  
25 statistical analysis includes at least one of principal  
26 components analysis, maximum likelihood classification  
27 and multivariate classification.

28

29 58. A method as claimed in any one of Claims 55 to 57,  
30 wherein said step of analysing said energy-frequency  
31 spectrum comprises frequency classification using  
32 energy bins.

1       59. A method as claimed in any one of Claims 55 to 57,  
2       wherein said step of analysing said energy-frequency  
3       spectrum comprises energy classification using  
4       frequency bins.

5

6       60. A method of identifying an unknown subject  
7       comprising the steps of:

8              obtaining an energy-frequency signature of said  
9       subject using the method of any one of Claims 55 to 59;  
10      and

11             comparing said energy-frequency signature of the  
12      unknown subject to a database of energy-frequency  
13      signatures of known subjects previously obtained using  
14      the method of any one of Claims 55 to 59.

15

16       61. A method as claimed in any one of Claims 55 to 60,  
17      implemented using a radar system as claimed in Claim 53  
18      or 54.

19

20       62. A radar system as claimed in Claim 53 or 54,  
21      wherein said data processing means is adapted to  
22      perform the method of any of Claims 55 to 60.

23

24

(19) World Intellectual Property Organization  
International Bureau



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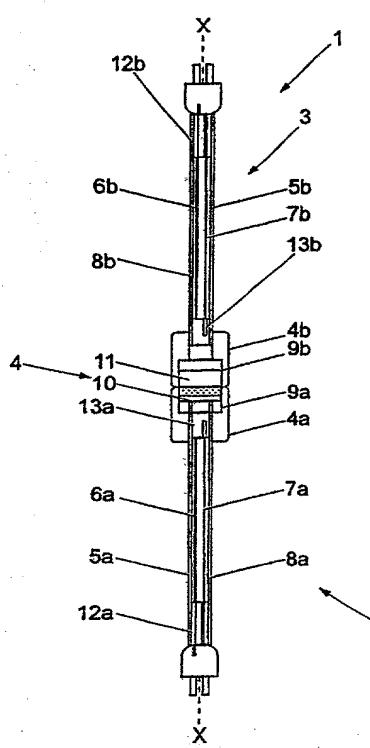
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[Continued on next page]

(54) Title: RADAR APPARATUS FOR IMAGING AND/OR SPECTROMETRIC ANALYSIS AND METHODS OF PERFORMING IMAGING AND/OR SPECTROMETRIC ANALYSIS OF A SUBSTANCE FOR DIMENSIONAL MEASUREMENT, IDENTIFICATION AND PRECISION RADAR MAPPING



(57) Abstract: Radar apparatus and methods of use thereof for imaging and/or spectrometric analysis. The invention employs pulsed radar signals for magnifying, imaging, scale measuring, identifying and/or typecasting the composition of substances by radargrammetric imaging and/or statistical analysis of energy/frequency spectrums. The invention may be used to locate and/or distinguish a substance from other substances, to image a substance/feature and to monitor the movement of an imaged substance/feature. The systems and methods can be adapted for a variety of applications at a wide range of scales and distances, from large scale, long range applications such as geophysical imaging/analysis, to the small scale such as material typecasting applications and small scale (including microscopic) imaging/analysis, including biological and medical imaging and diagnostic applications. The invention includes novel antenna assemblies and novel data processing techniques.

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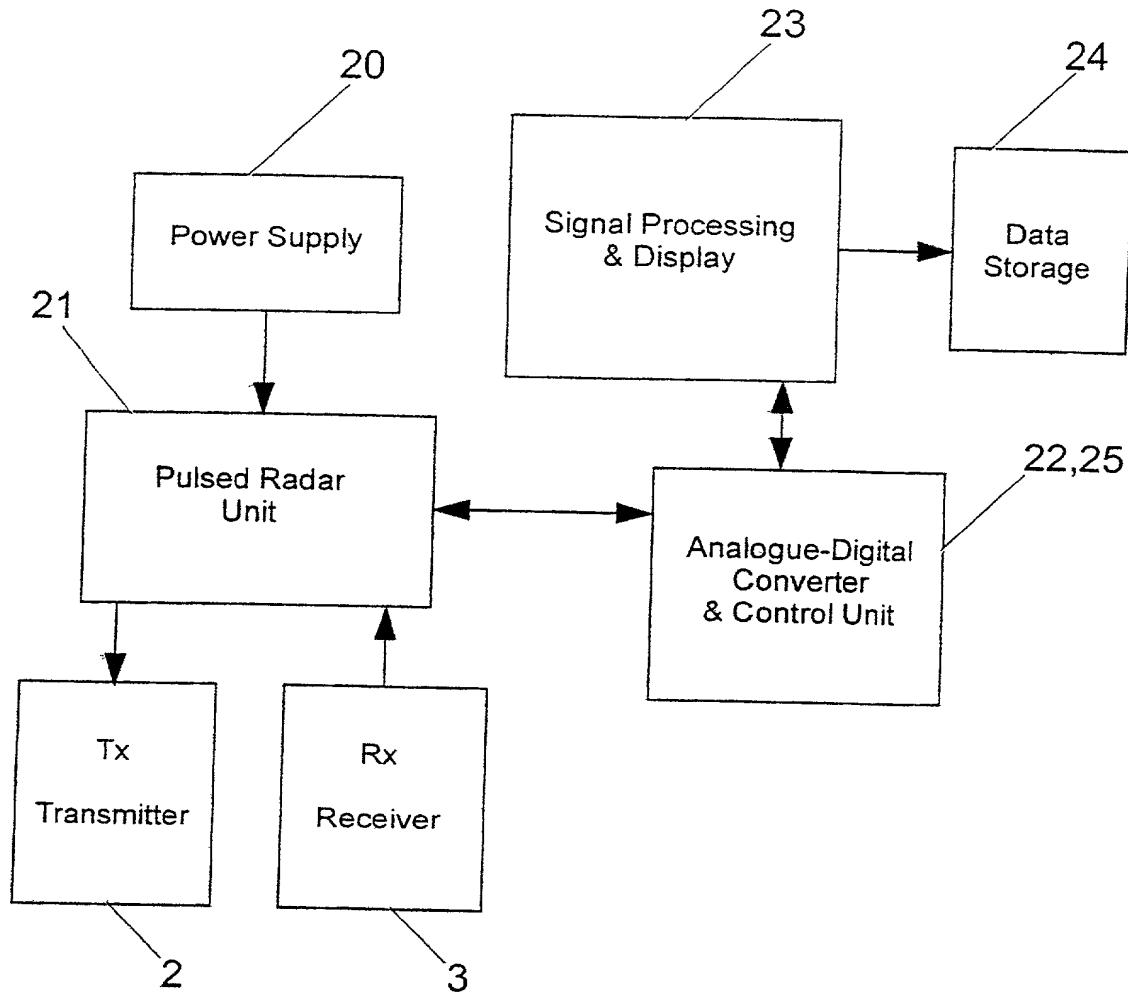


Fig. 1

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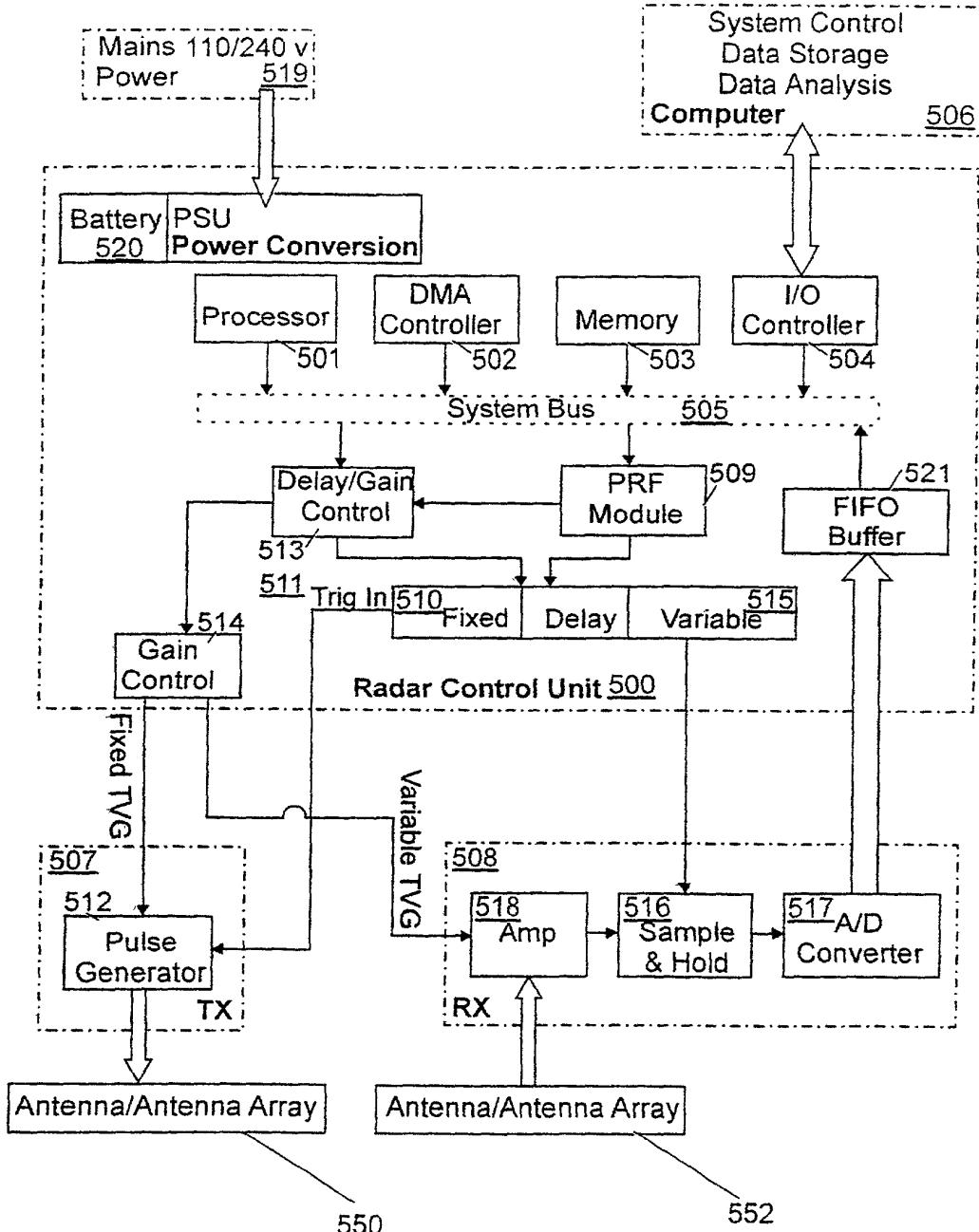


Fig. 2

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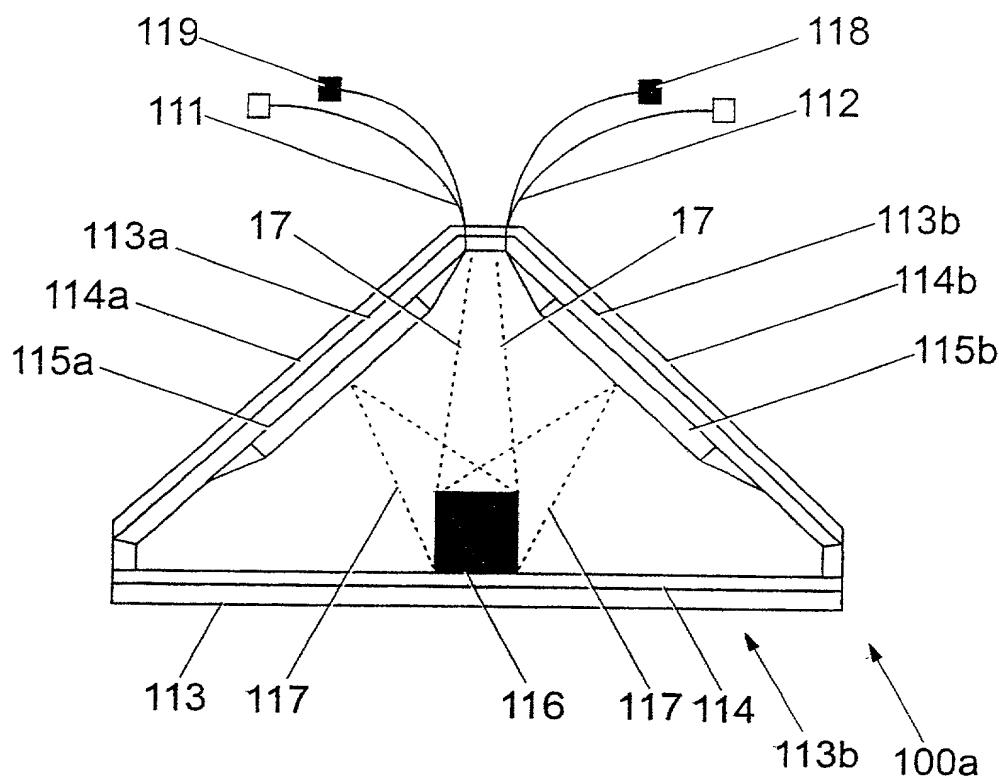


Fig. 3A

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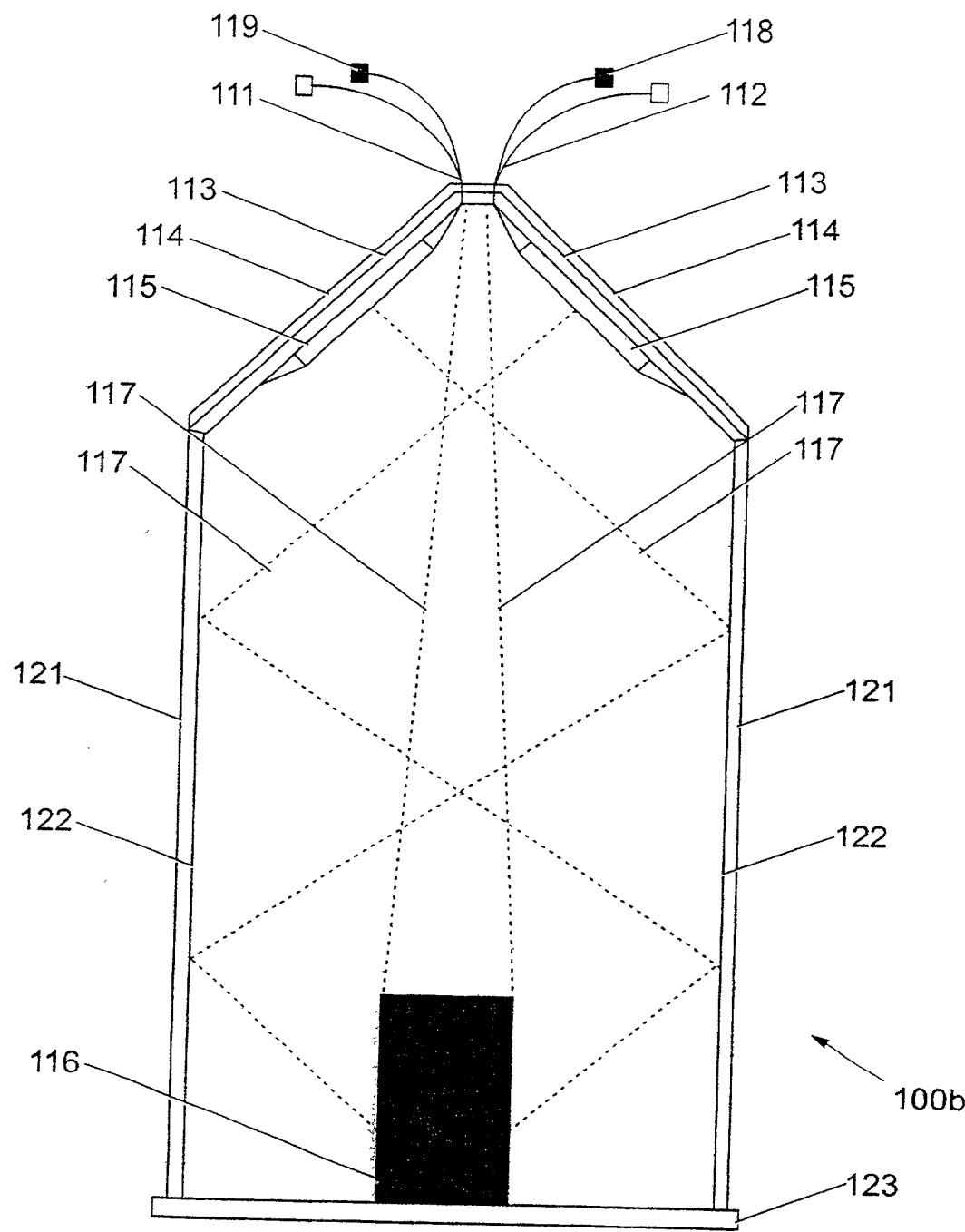


Fig. 3B

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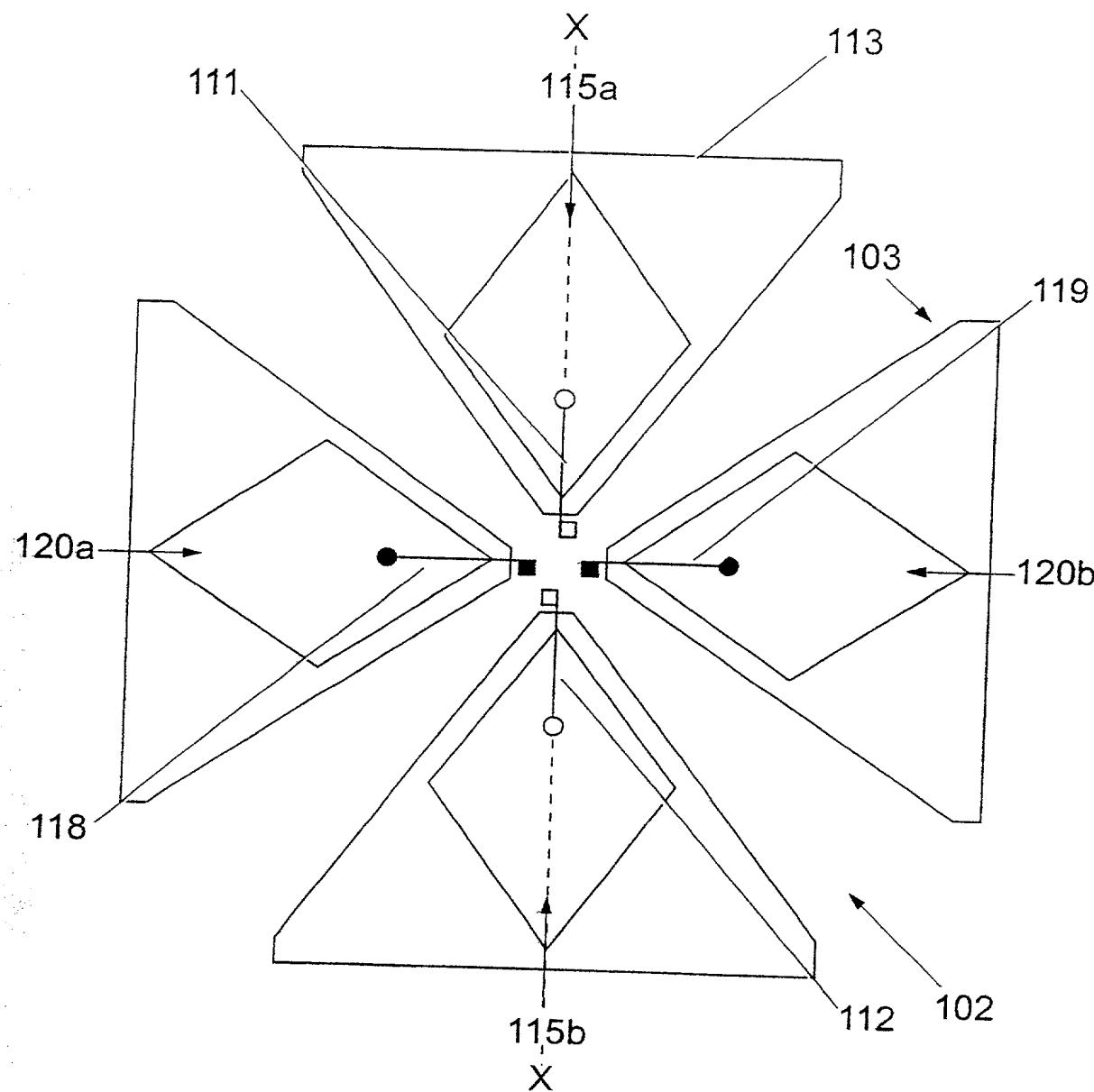


Fig. 4

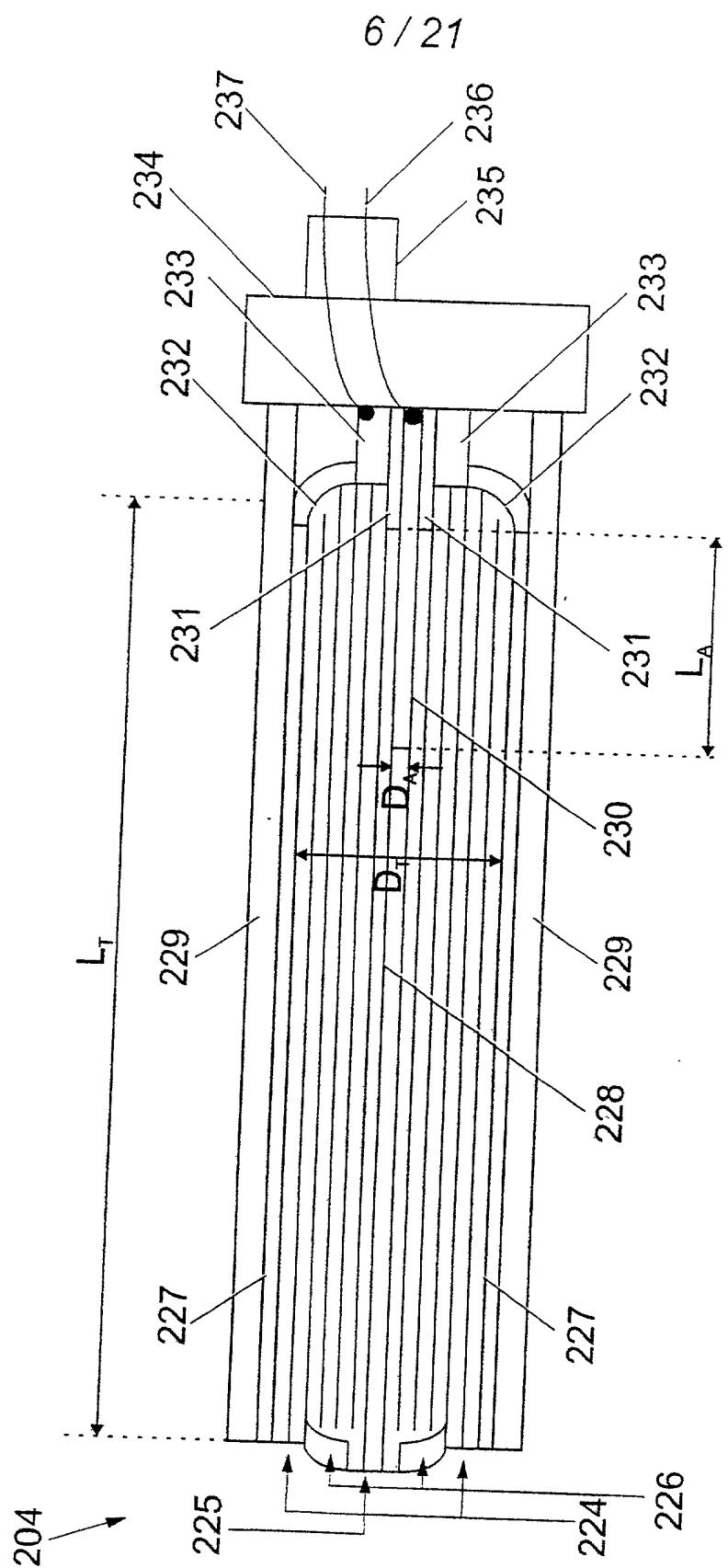


Fig. 5A

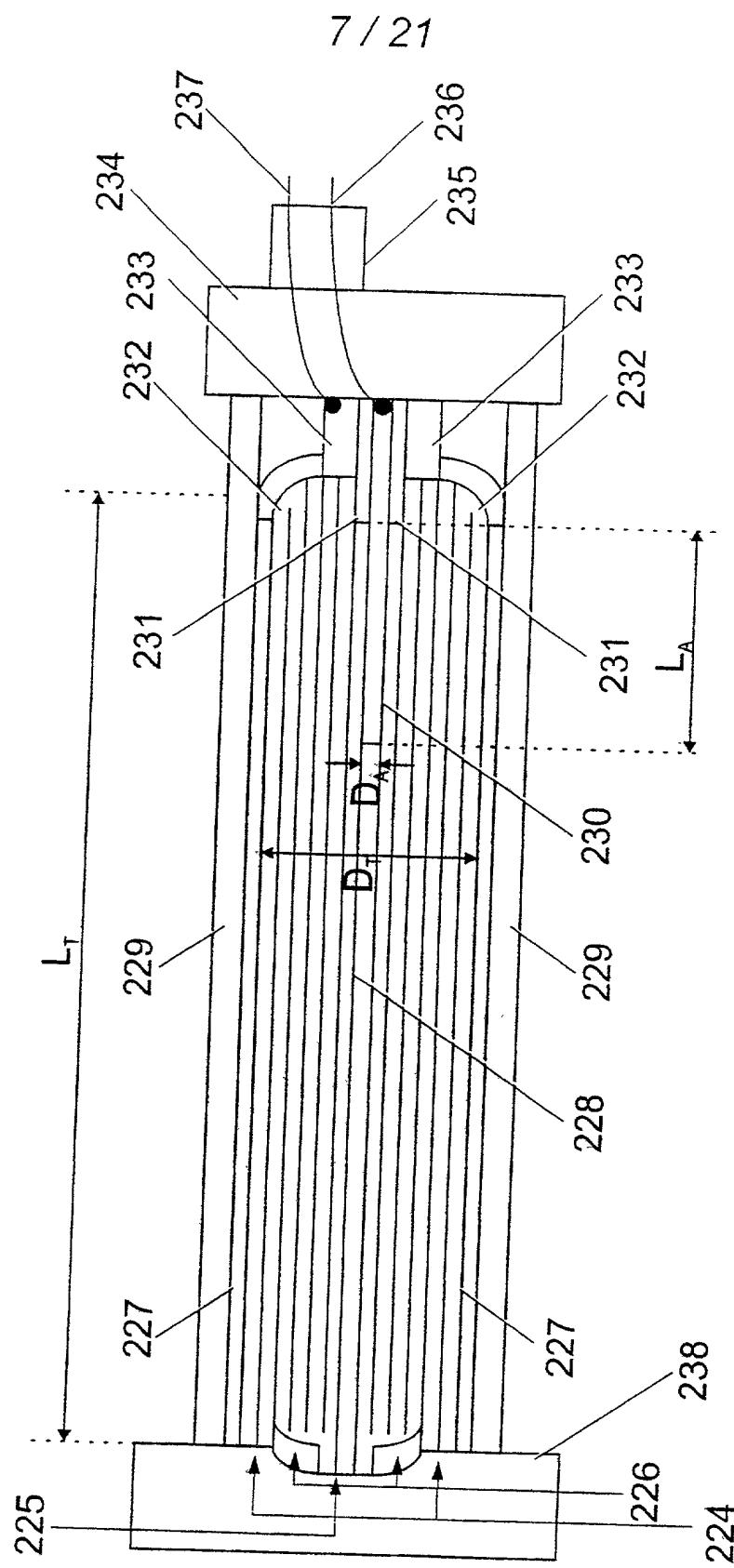


Fig. 5B

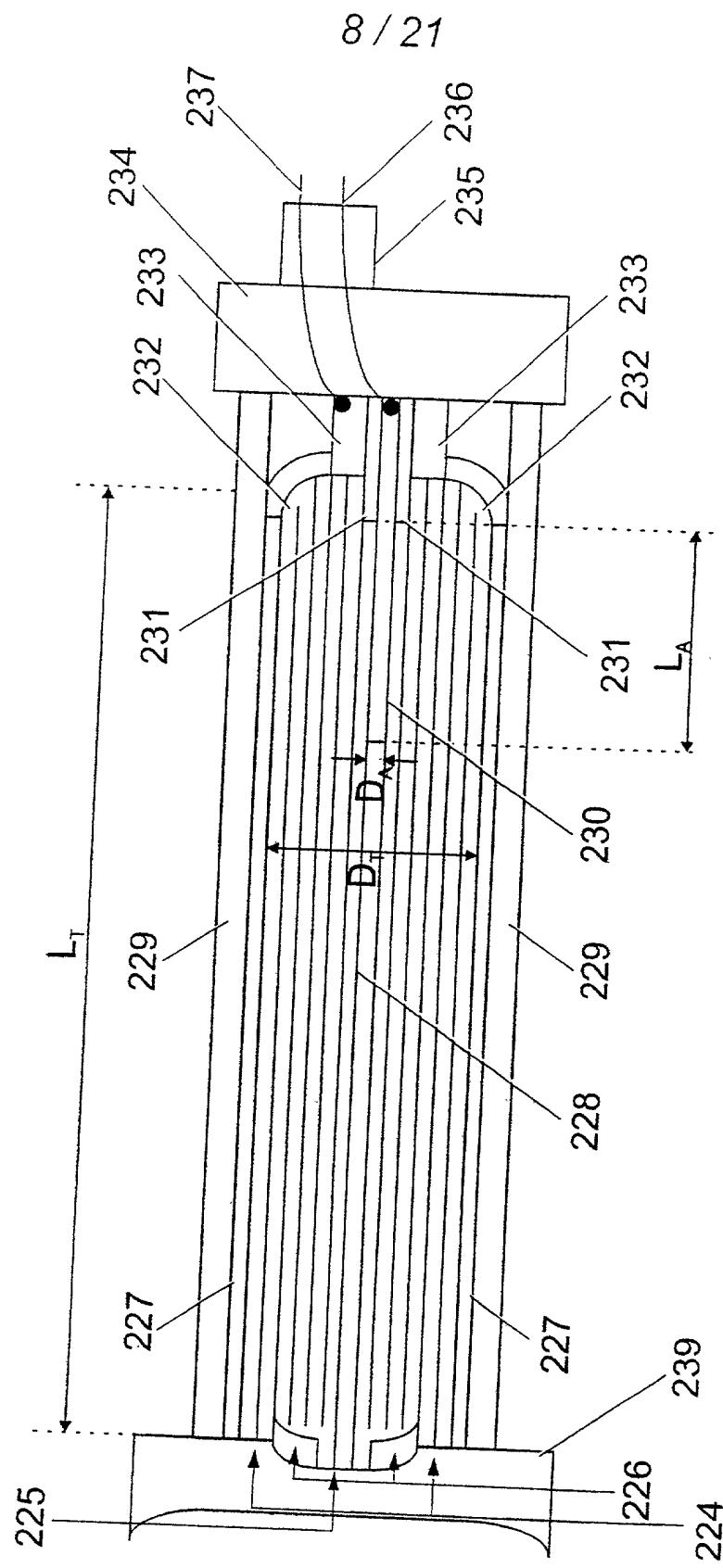


Fig. 5C

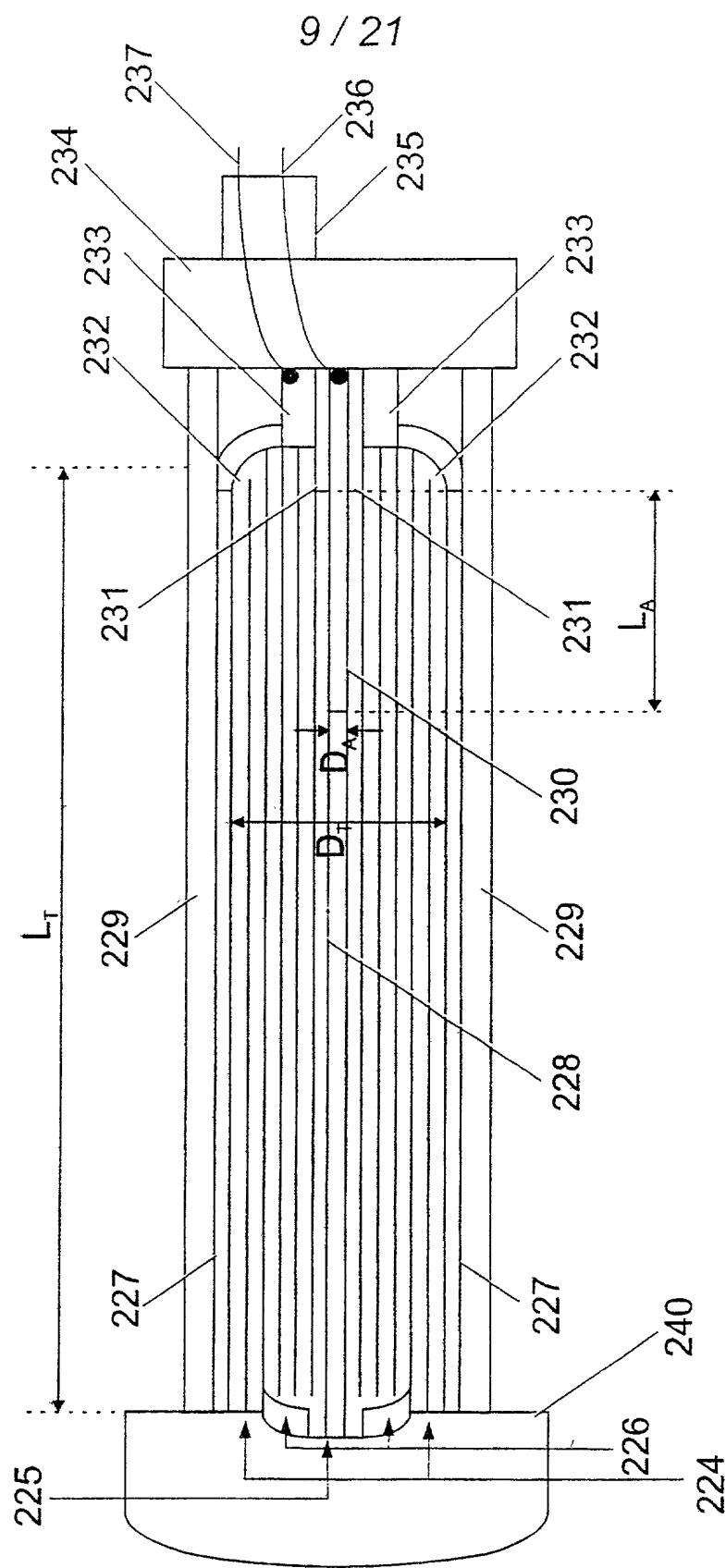


Fig. 5D

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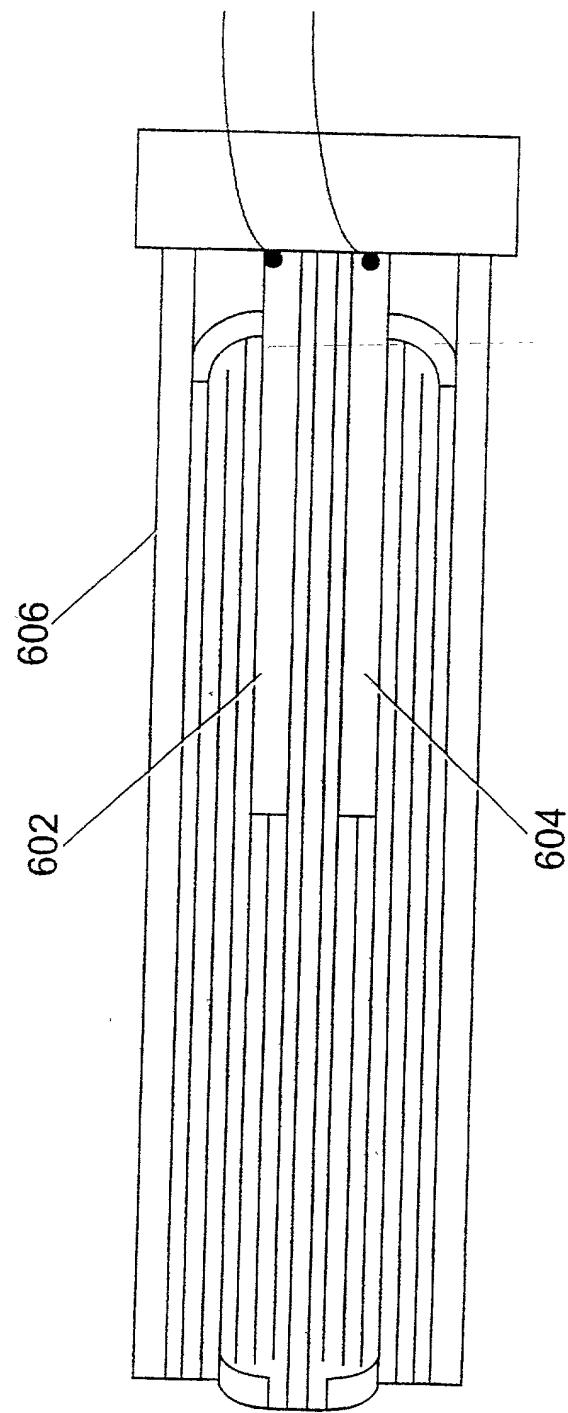
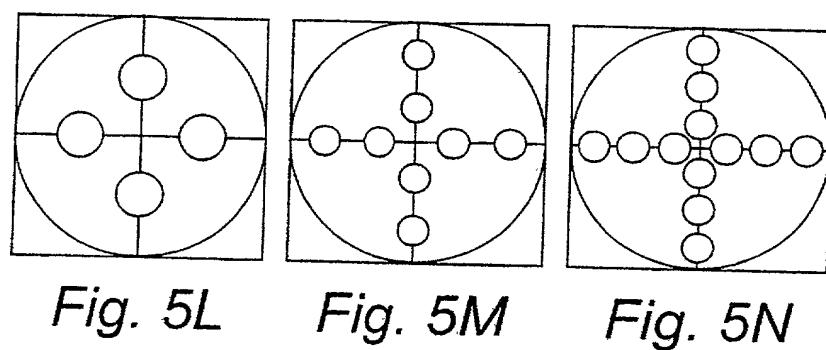
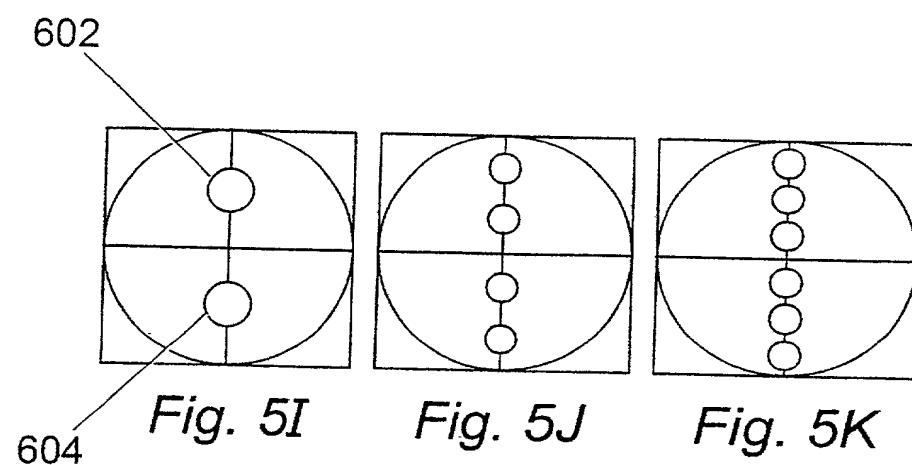
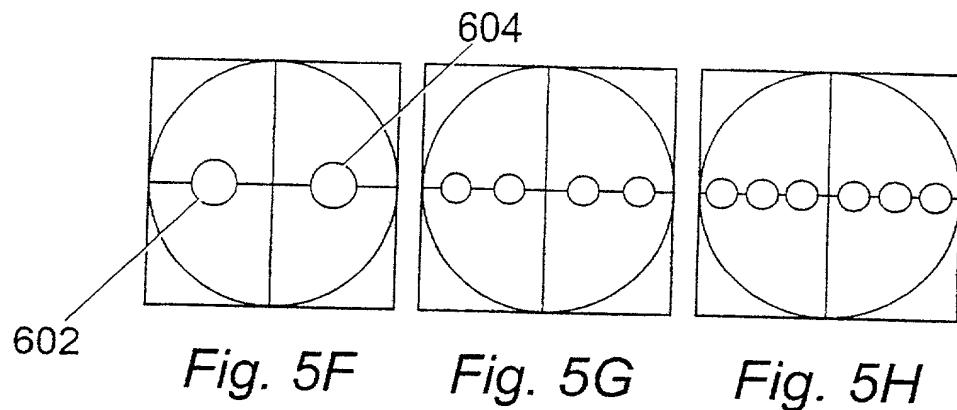


Fig. 5E

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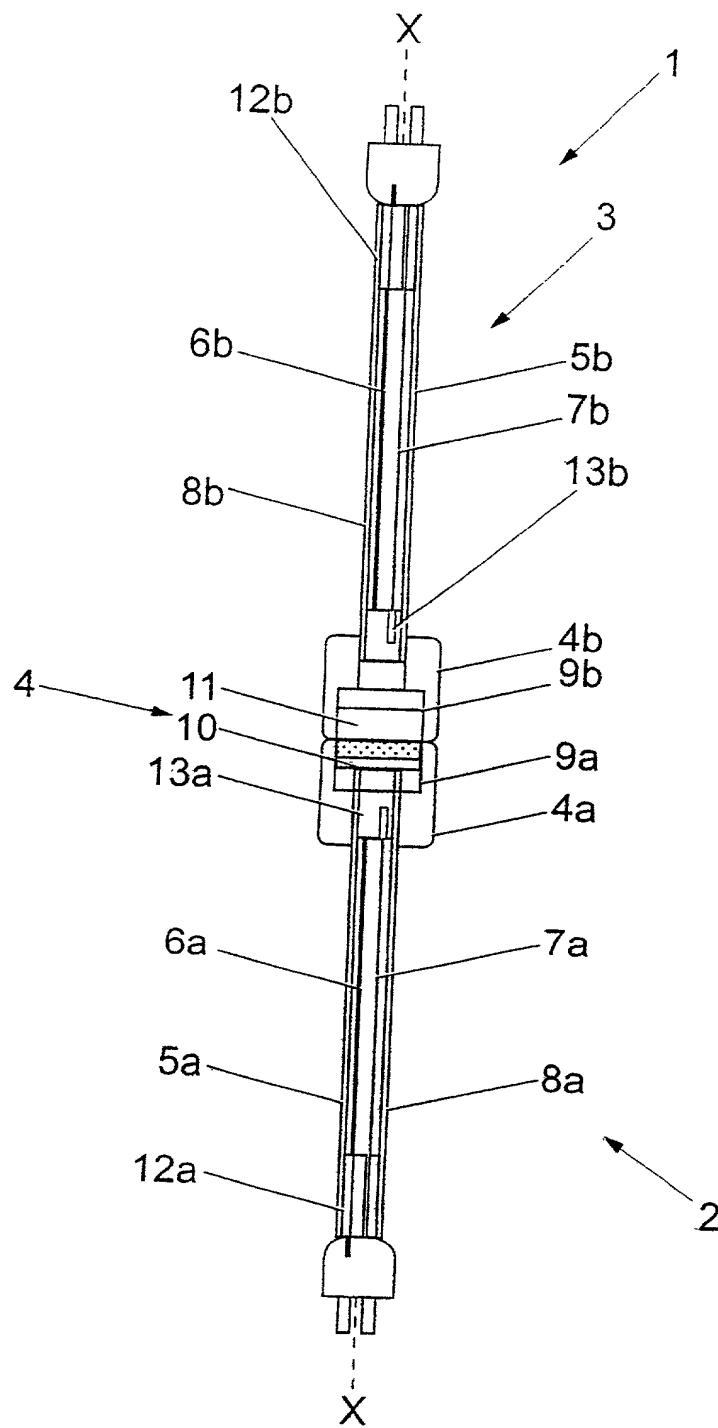


Fig. 6A

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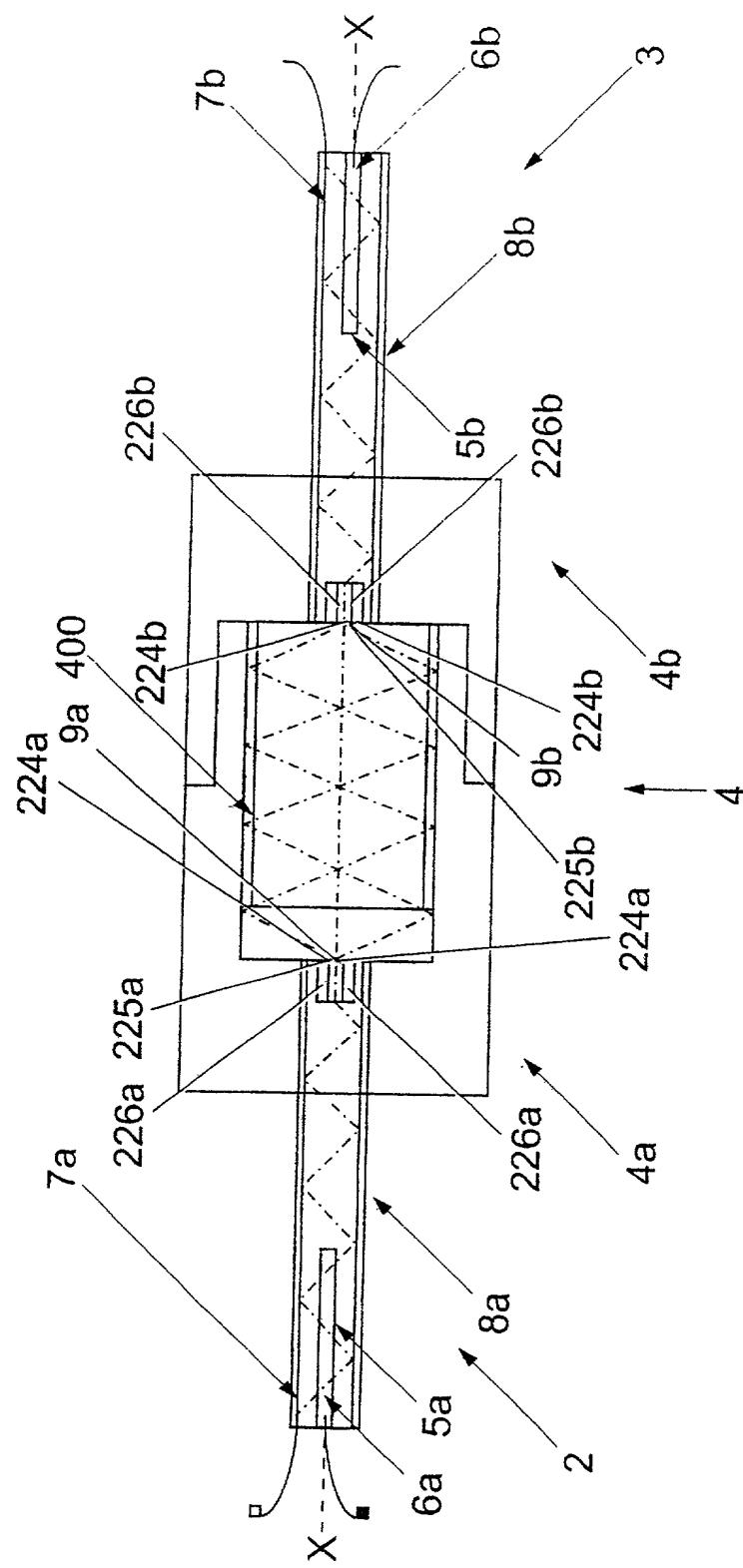


Fig. 6B

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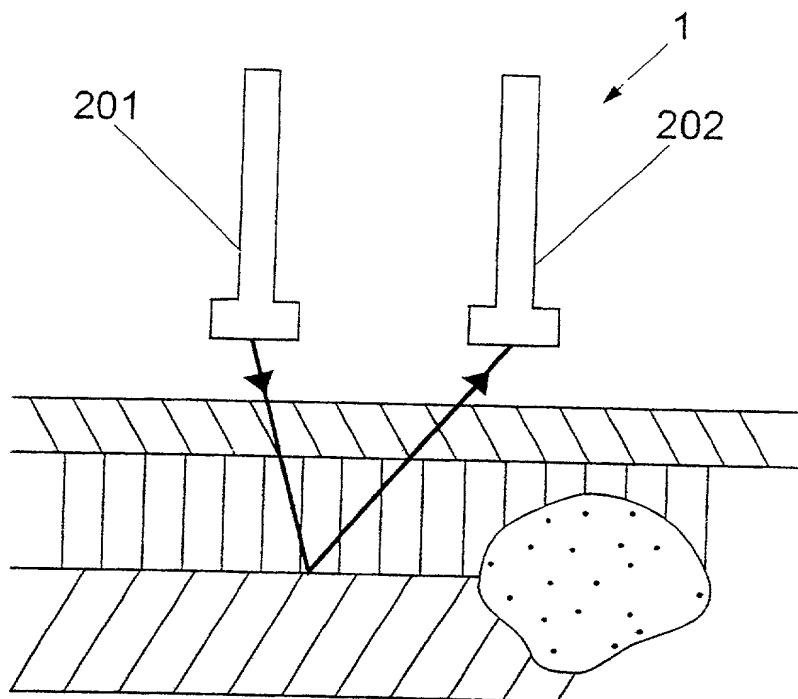


Fig. 7A

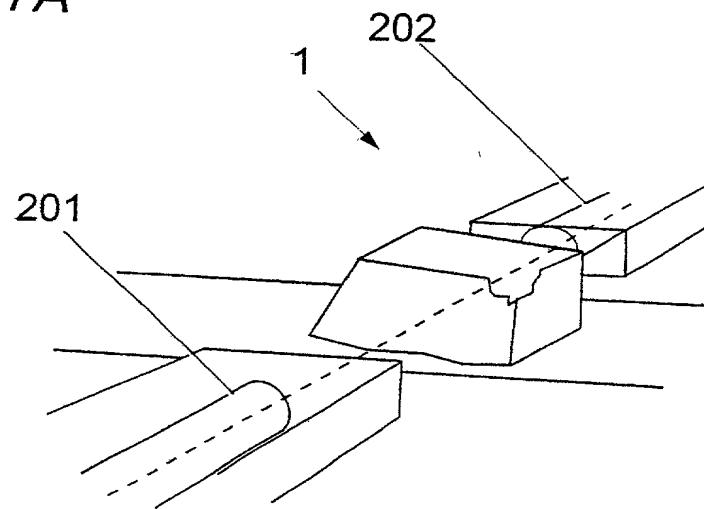


Fig. 7B

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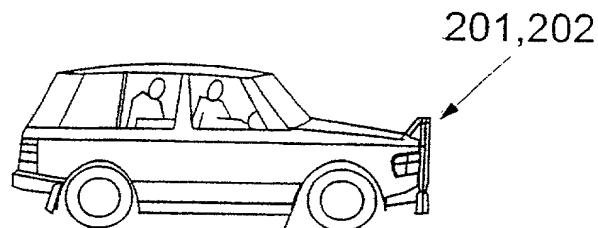
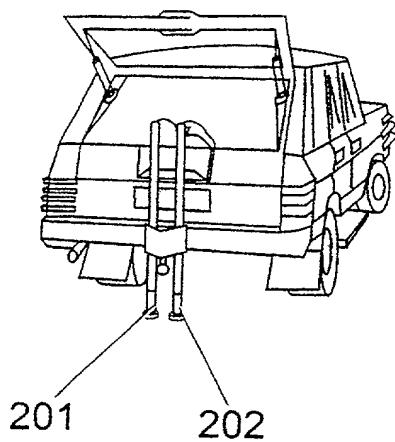


Fig. 8A

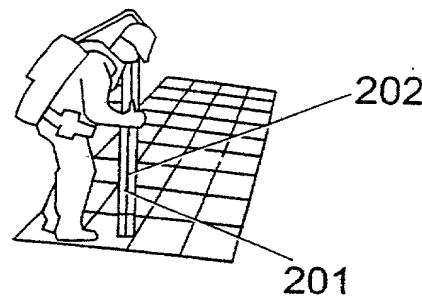
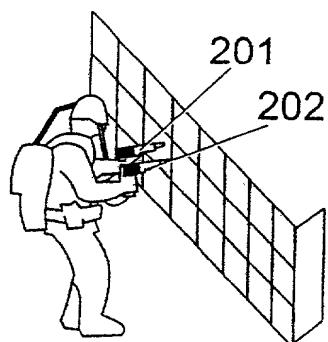


Fig. 8B

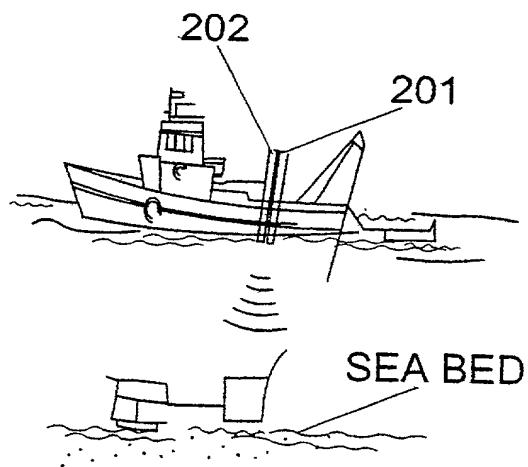
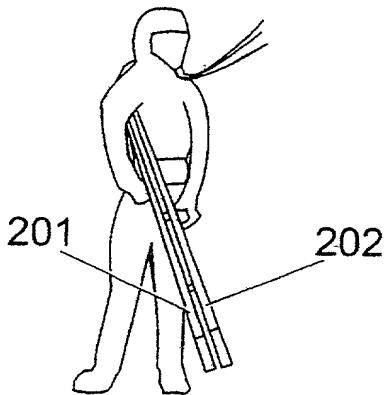


Fig. 8C

Fig. 8D

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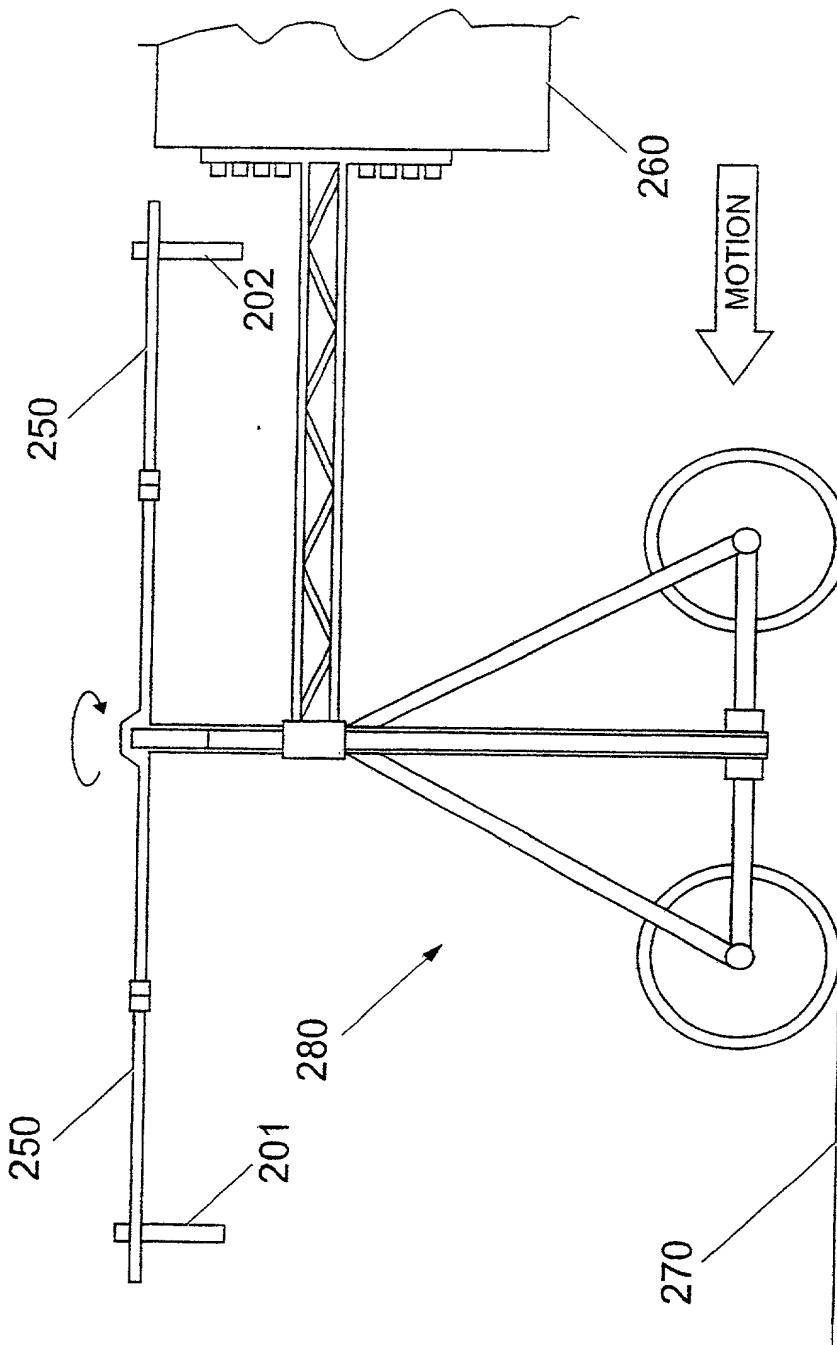


Fig. 9

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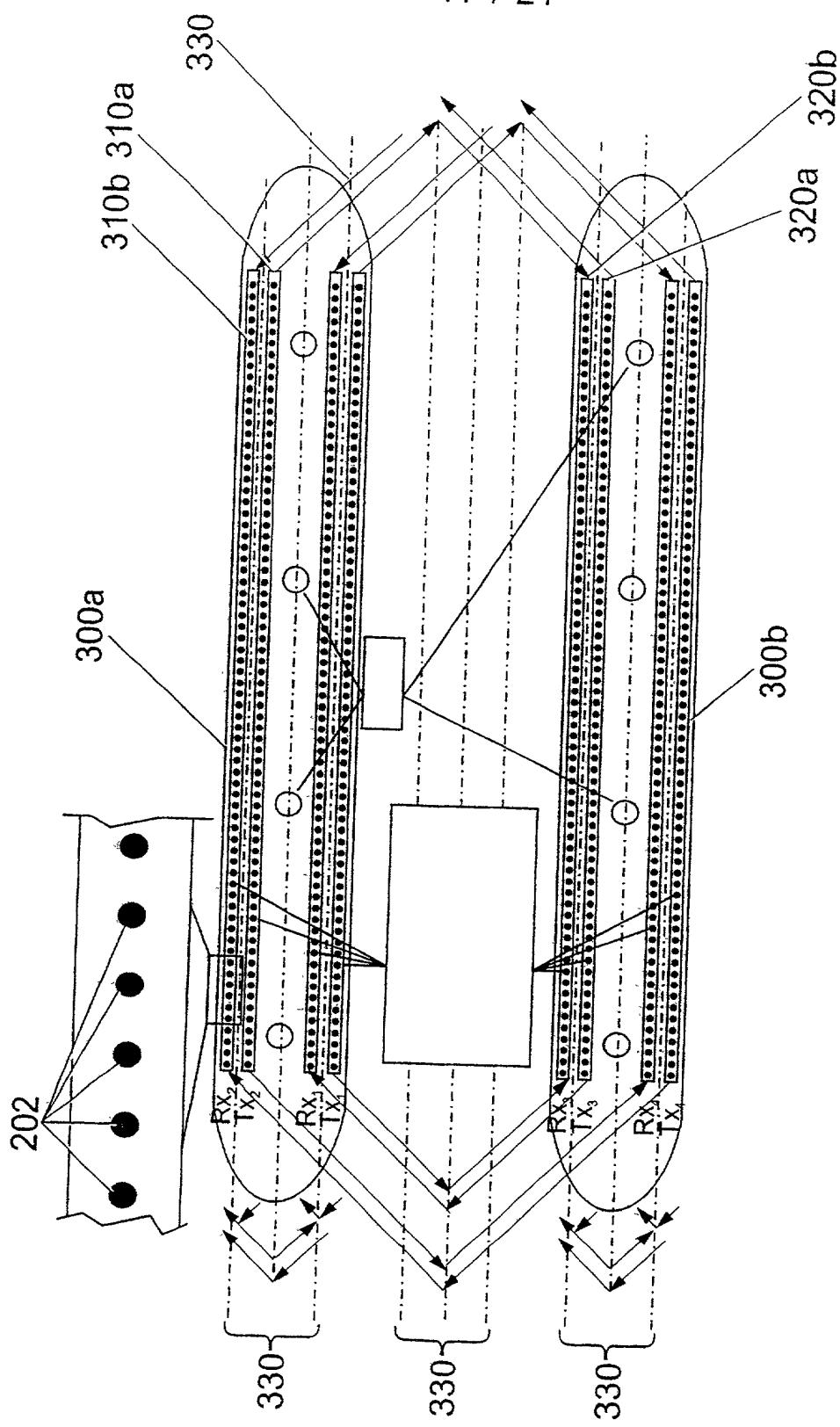


Fig. 10

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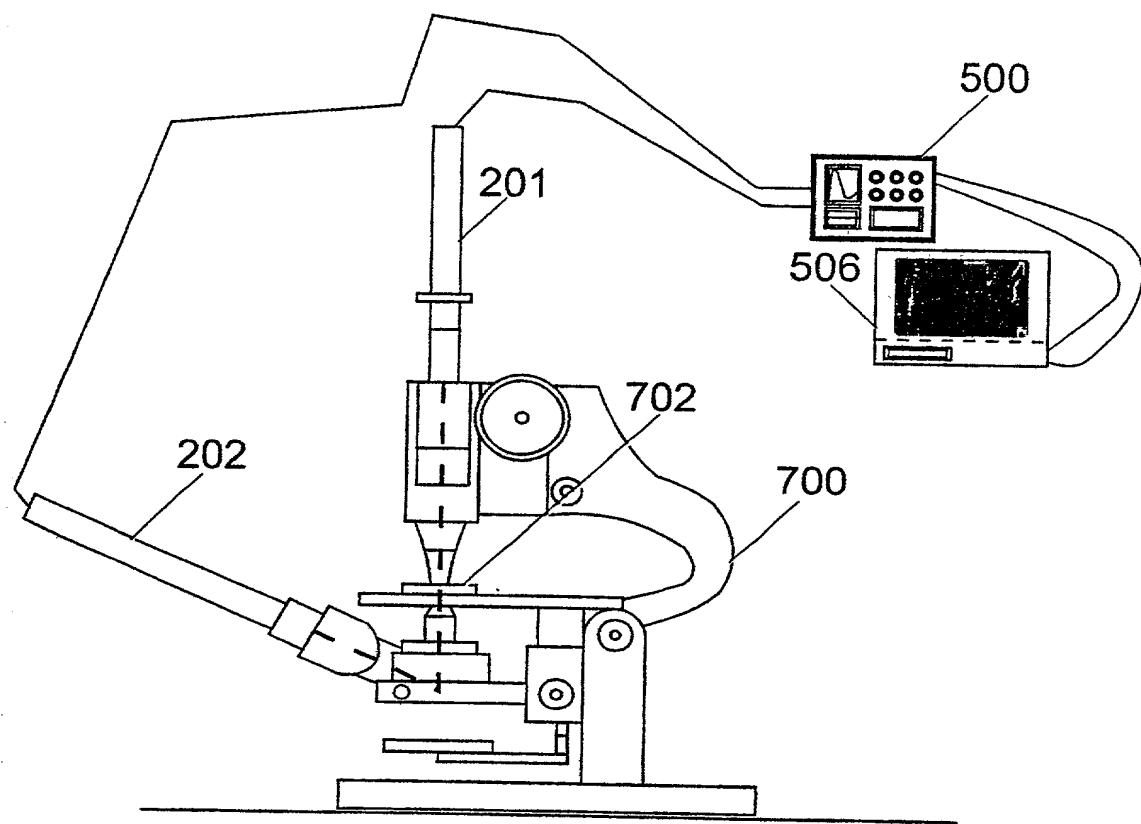


Fig. 11A

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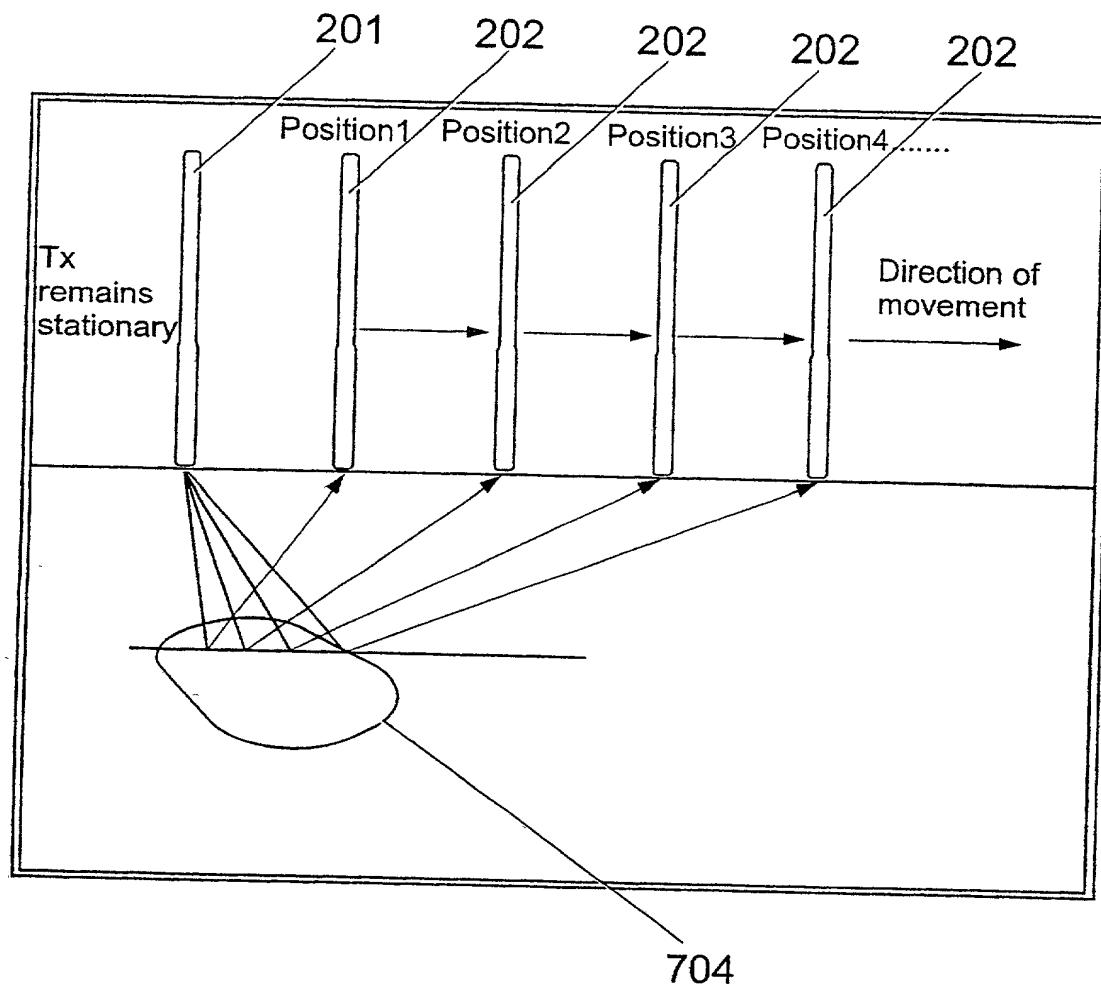


Fig. 11B

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MODE	Resolution Time (ps)	Resolution Space (m) (in salt water)	PRF (kHz)	Pw (ns)	TR (ns)	Fmax (MHz)	Fmin (MHz)	Ptr	ScanRate (traces/s)	1/SR (Sdelay)	Ts (ns)
A1	50	0.001667	100	0.1	2	10000	1000	40	2500	0.0004	0.05
A2	50	0.001667	100	0.1	5	10000	1000	100	1000	0.001	0.05
A3	100	0.001667	100	0.1	10	5000	500	100	1000	0.001	0.05
A4	250	0.001667	100	0.1	15	2000	200	60	1667	0.0006	0.1
A5	500	0.001667	100	0.1	25	1000	100	50	2000	0.0005	0.25
B1	250	0.01667	100	1	2000	2000	125	8000	12.5	0.08	0.5
B2	500	0.01667	100	1	4000	1000	62.5	8000	12.5	0.08	0.5
B3	625	0.01667	100	1	6000	800	50	9600	10.4	0.096	0.625
B4	1250	0.01667	50	1	8000	400	25	6400	7.8125	0.128	1.25
B5	2500	0.01667	25	1	10000	200	12.5	4000	6.25	0.16	2.5
C1	2500	0.16667	50	10	20000	200	12.5	8000	0.625	1.6	2.5
C2	5000	0.16667	25	10	40000	100	6.25	8000	0.3125	3.2	5
C3	10000	0.16667	12.5	10	80000	50	2.25	8000	0.15625	6.4	10
C4	40000	0.16667	6.25	10	160000	12.5	1	40000	0.15625	6.4	40
C5	62500	0.16667	3.125	10	250000	12.5	1	400000	0.078125	12.8	40

Sampling Rate =  $F_s = 2^* F_{max}$   
 Range for all generic types =  $1/4 F_{max} - 4 F_{max}$   
 Ptr = Time Range(TR)/Sampling Time (ts)  
 Sampling Time =  $T_s = 1/2 F_{max}$ , time occupied by 1 pixel in the y-direction going down the trace

Fig. 12

Ptr = number of pixels per trace  
 PRF = Pulse Repetition Frequency  
 Pw = Pulse Width  
 TR = Time Range  
 Fmax = Maximum Frequency  
 Fmin = Minimum Frequency  
 Resolution Time = time between pixels going down the trace  
 SR = Sampling Rate

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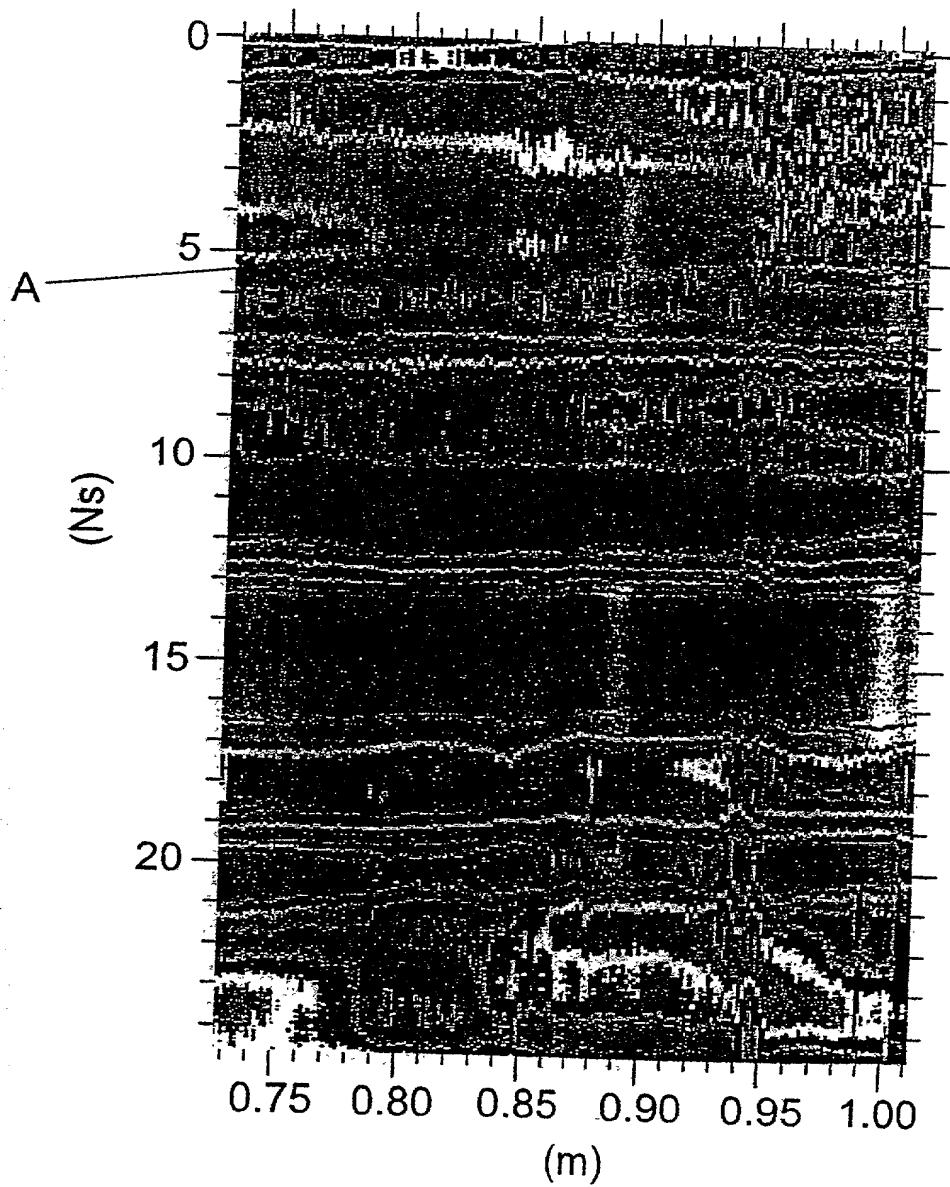


Fig. 13

## **DECLARATION AND POWER OF ATTORNEY**

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**"Radar Apparatus for Imaging and/or Spectrometric Analysis and Methods of Performing Imaging and/or Spectrometric Analysis of a Substance for Dimensional Measurement, Identification and Precision Radar Mapping"**

the specification of which (check one)

[ ] is attached hereto.

was filed on September 7, 2000 as United States Application Serial No. \_\_\_\_\_ or PCT International Application No. PCT/GB00/03431 and was amended on \_\_\_\_\_ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code §119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

PRIORITY FOREIGN APPLICATION(S)

			Priority Claimed
<u>9921042.9</u> (Number)	<u>United Kingdom</u> (Country)	<u>07 September 1999</u> (Day/month/year filed)	Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>
<u>PCT/GB00/03431</u> (Number)	<u>PCT</u> (Country)	<u>07 September 2000</u> (Day/month/year filed)	Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States provisional application(s) listed below.

(Application Number) (Filing Date)

(Application Number) (Filing Date)

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.) (Filing Date) (Status)(patented,  
pending, abandoned)

(Application Serial No.) (Filing Date) (Status)(patented,  
pending, abandoned)

And I hereby appoint Arthur H. Seidel, Registration No. 15,979; Gregory J. Lavorgna, Registration No. 30,469; Daniel A. Monaco, Registration No. 30,480; Thomas J. Durling, Registration No. 31,349; John J. Marshall, Registration No. 29,671; Joseph R. DelMaster, Jr., Registration No. 38,123; Robert E. Cannuscio, Registration No. 36,469, and George A. Frank, Registration No. 26,708, my attorneys or agents with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

Address all correspondence to Gregory J. Lavorgna at Drinker Biddle & Reath LLP, One Logan Square, 18<sup>th</sup> & Cherry Streets, Philadelphia, PA 19103-6996. Address all telephone calls to Gregory J. Lavorgna at 215-988-3309 (telefax: 215-988-2757).

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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